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METAL PROGRESS

OCTOBER 1936

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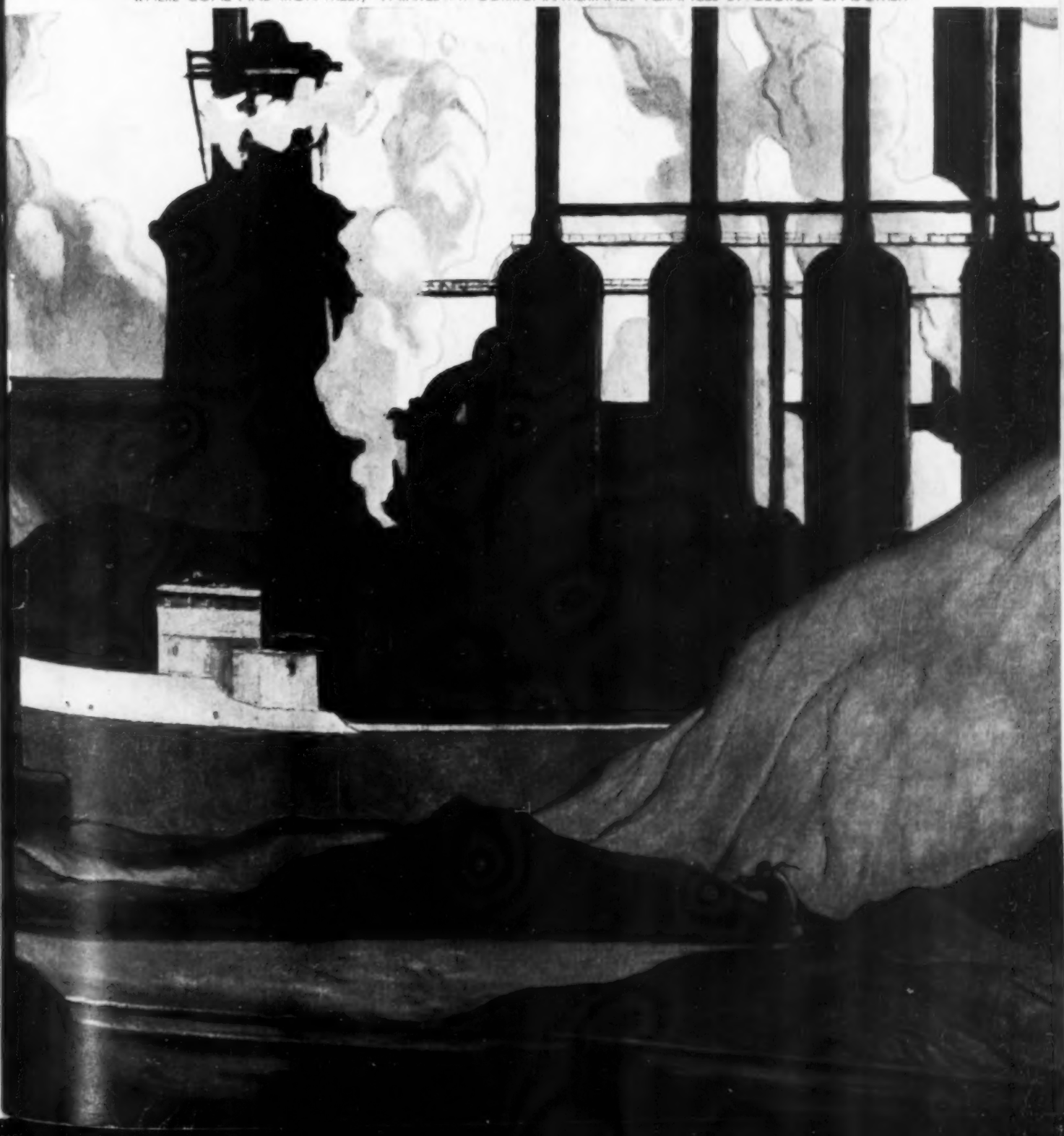

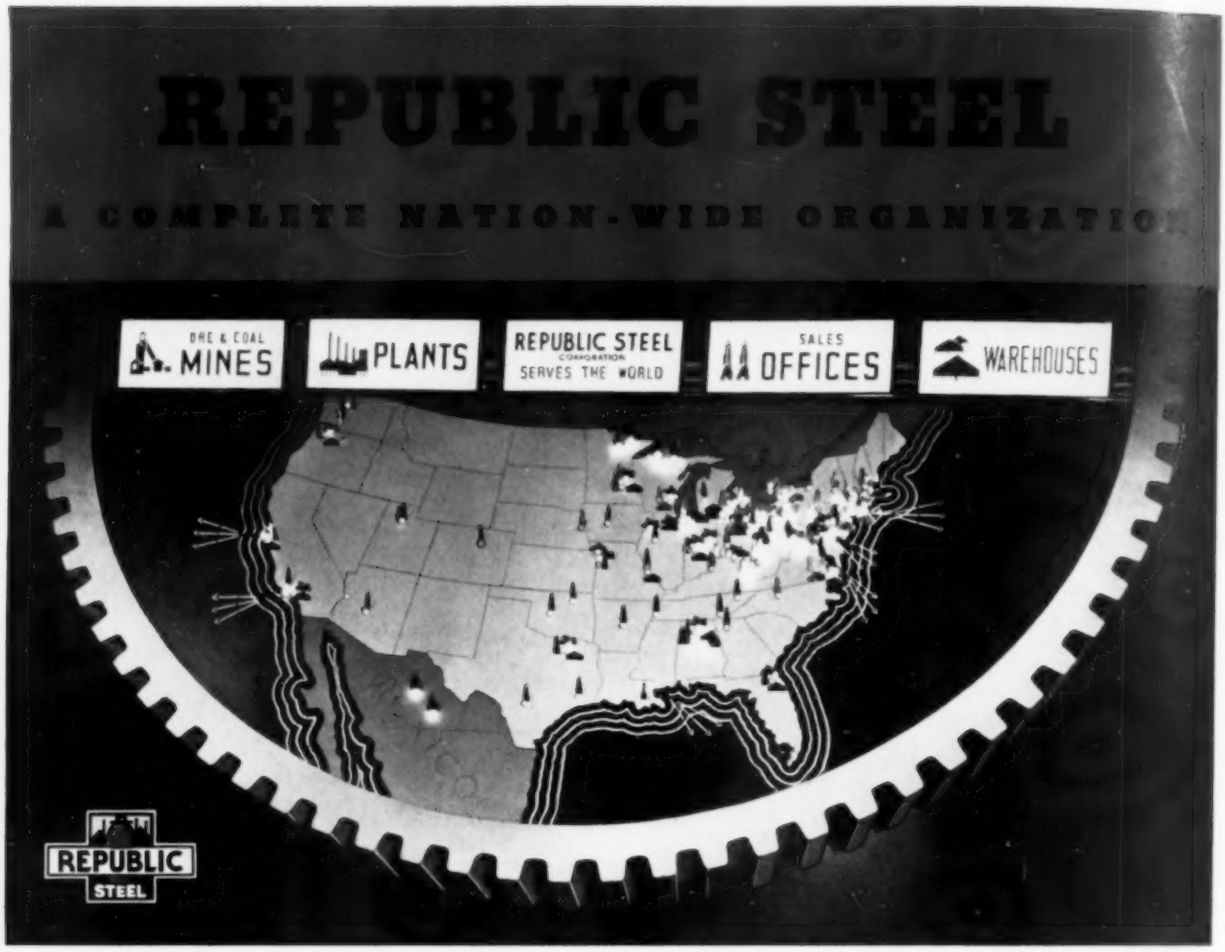

GEARED TO MEET THE STEEL NEEDS OF INDUSTRY

● This huge map—part of the Republic Steel exhibit at the 18th National Metal Congress at Cleveland—demonstrates the vast resources, facilities and distribution centers of Republic. It illustrates careful planning and the use of strategic locations. It symbolizes, by the huge gear that encompasses the map, a complete nation-wide organization, with each tooth a unit vitally important in the production and distribution of better steels and steel products—in the maintenance of Republic's reputation as the world's largest maker of alloy and special steels and as a major producer of high quality carbon steels.

You'll find this map in Booth E-6. You'll also find in attendance engineers and metallurgists from Republic's famous metallurgical laboratories—men whose life's work is the development and application of steels to meet your most exacting requirements. They will tell you about Republic products—about the new Republic steels that are effecting economies in construction and maintenance and increasing manufacturers' sales through lighter weight; greater strength; increased resistance to corrosion, high temperatures, shock, vibration and wear; better performance; and more beautiful finish. They will discuss your problems—without any obligation, except their own to help you find the most efficient and economical steel for your purpose.

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METAL PROGRESS

Vol. 30 *October, 1936* *No. 4*

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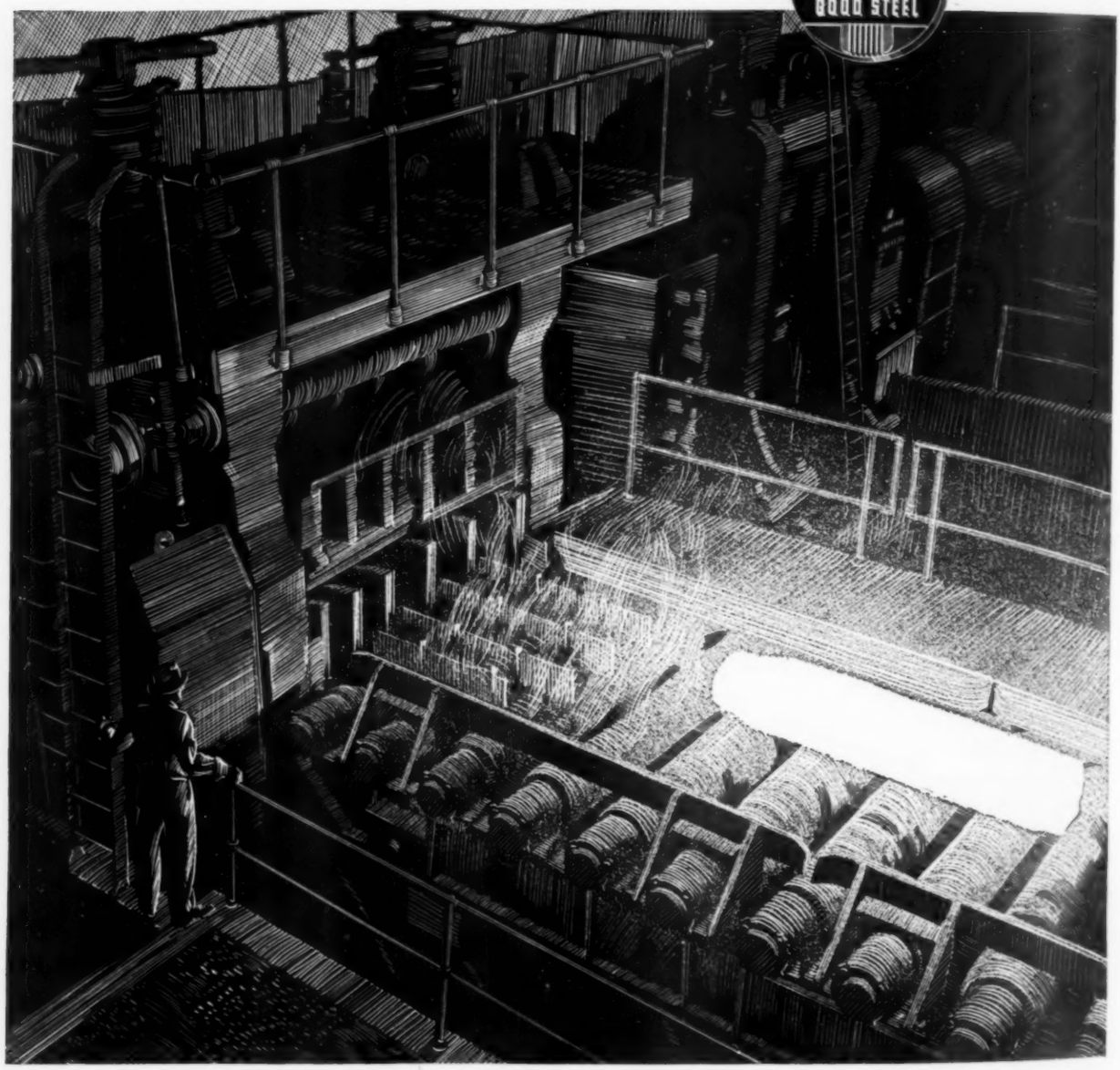

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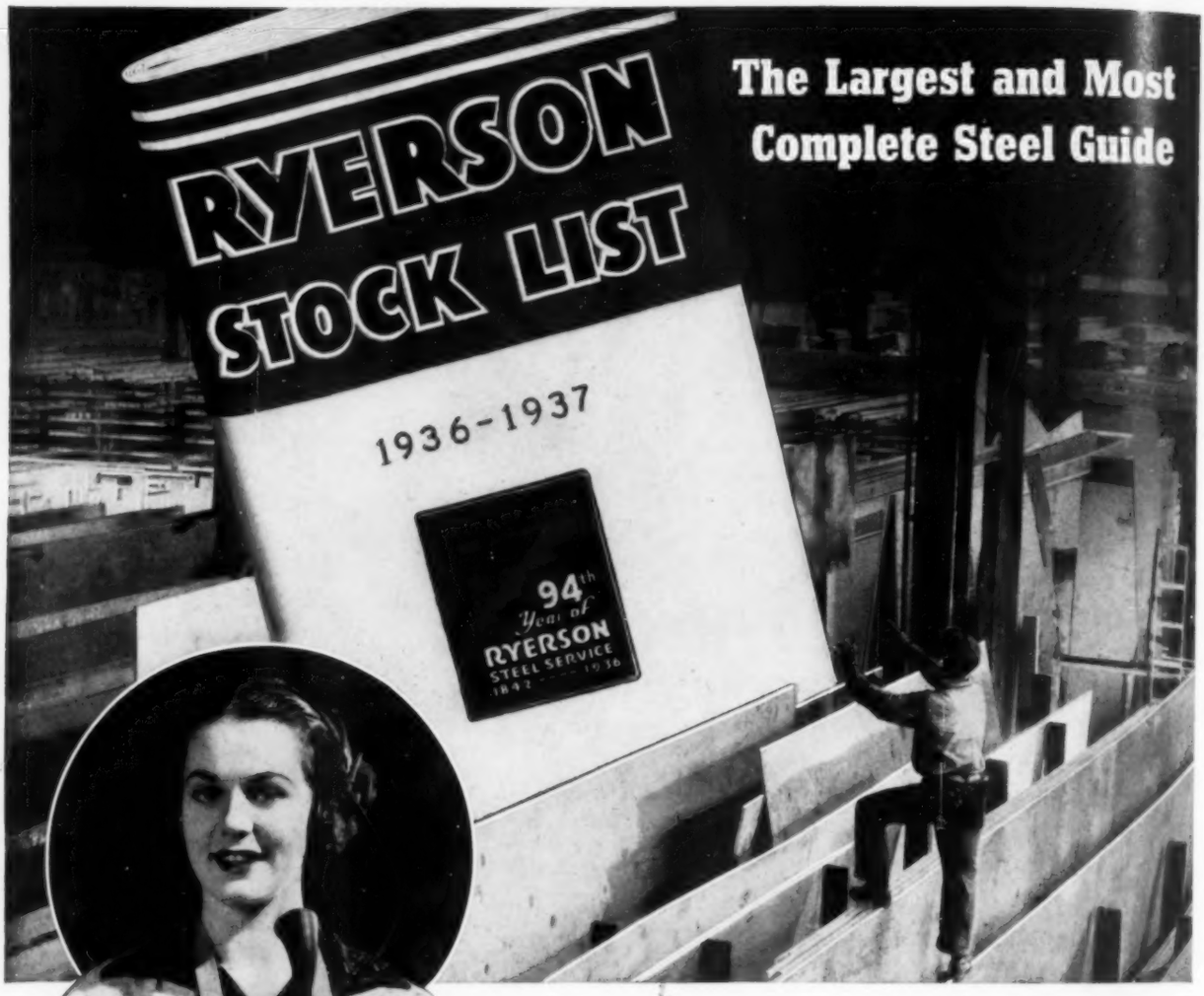
LEVELAND, OHIO

OCT. 19 to 23, 1936



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o o o The Ryerson Stock List is your guide to the largest and most diversified stocks of steel in the country. It shows sizes, weights, extras and other information useful to the steel buyer. In it you are sure to find the kind and quality of material best suited to your needs. And the Ryerson organization will cut, form or do whatever is required and deliver the steel or allied products in record time.

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METAL PROGRESS

1918 • • 1936

TO MEMBERS AND FRIENDS,

American Society for Metals:

This issue of "Metal Progress," by its unusual size and variety, will foreshadow the importance of the National Metal Congress and Exposition, sponsored by our Society, to be held in Cleveland the week of October 19. It takes no prophet to forecast that all records for this event are about to be broken. A cordial invitation to attend is extended to all those interested in the production and use of metals.

The American Society for Metals is now 18 years old. It has successfully passed difficult years of development and is coming of age. We look forward hopefully to the even more vigorous years of young manhood. We may be pardoned the pride we feel in the quality and value of our organization, perhaps best measured by the increase in membership. Reaching an all-time high in January 1935, on our way up out of the depression, we have steadily added members month by month until now we have gained a further twenty per cent in numbers. This is the best kind of proof that the American Society for Metals is successfully filling a need in our national economy.

The present issue of "Metal Progress" is designed to appraise this value in another way — by devoting most of the articles to reviewing the contributions to technical advance made in the publications in the past two years. The record is obviously impressive and should impress anyone that much valuable information and inspiration is to be acquired by attending the Cleveland Congress.

The Metal Congress is well named, for no less than four other national societies have also arranged technical programs during the week. In addition to the usual technical sessions, our own Society is presenting a notable symposium on the hot working and cold working of metals, two lecture courses — one on physical testing, another on X-ray analysis — both fundamental means of metallurgical control. The Campbell Memorial Lecturer will consider some problems connected with high speed steel — but complete information about the program is contained in the pages immediately following.

Members of the local chapter extend a hospitable welcome. Hundreds of engineers, metallurgists and researchers have generously contributed to make the technical programs outstanding in value. A thousand others have done their best to collect together and exhibit the most modern equipment, materials, methods and supplies used by our industry.

Truly anyone will be greatly benefited by coming to Cleveland and partaking of this rich fare, so carefully prepared. Let me urge you to come!

R. S. Archer

President

THE AMERICAN SOCIETY FOR METALS

American Society for Metals

THE OBJECT OF THE SOCIETY SHALL BE TO PROMOTE THE ARTS AND SCIENCES CONNECTED WITH EITHER THE MANUFACTURE OR TREATMENT OF METALS, OR BOTH.

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HORACE H. LESTER	1925	HERBERT J. FRENCH	1930	JOSEPH V. EMMONS	1933
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WESLEY P. SYKES	1927	KARL HEINDLHOFER	1931	TRYGVE D. YENSEN	1935
OSCAR E. HARDER	1928	FRANCIS M. WALTERS	1932	NICHOLAS A. ZIEGLER	1935
		CYRIL WELLS	1932		

SAUVEUR ACHIEVEMENT MEDALISTS

ALBERT SAUVEUR 1934 ZAY JEFFRIES 1935

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WILLIAM S. BIDLE	1925	ROBERT G. GUTHRIE	1930	BENJAMIN F. SHEPHERD	1935

† Deceased.

CONSOLIDATED PROGRAM

National Metal Congress

AMERICAN SOCIETY FOR METALS — AMERICAN WELDING SOCIETY
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
AMERICAN SOCIETY OF MECHANICAL ENGINEERS
WIRE ASSOCIATION

Monday, Oct. 19, 1936

9:45 A.M. A.W.S. Annual Business Meeting; Hotel Cleveland
10:00 A.M. A.S.M. Session on Miscellaneous Alloys; Statler
12:00 M. National Metal Exposition opens; Auditorium
2:00 P.M. Simultaneous A.S.M. Sessions on Heat Treatment and Miscellaneous Alloys; Public Auditorium
2:00 P.M. A.W.S.; Metallurgy of Welding; Hotel Cleveland
3:30 P.M. W.A. Annual Meeting; Hotel Cleveland
4:30 P.M. Lecture Course, Physical Testing; Auditorium
8:00 P.M. Lecture Course, Radiography and X-Ray Analysis; Public Auditorium
10:00 P.M. National Metal Exposition closes

Tuesday, Oct. 20, 1936

9:30 A.M. W.A. Session on Cleaning and Furnace Atmospheres; Hotel Cleveland
9:45 A.M. A.W.S. Session on Fundamental Research; Hotel Cleveland
10:00 A.M. A.S.M. Session; Fine-Grained Steel; Hotel Statler
10:00 A.M. Simultaneous A.I.M.E. Sessions on Aging of Metals and Blast Furnace Practice; Hotel Statler
12:00 M. National Metal Exposition opens; Auditorium
2:00 P.M. A.S.M. Session on Stainless Steel; Auditorium
2:00 P.M. A.I.M.E. Session on Openhearth; Hotel Statler
2:00 P.M. A.W.S.; Fundamental Research; Hotel Cleveland
2:00 P.M. W.A. Session on Springs and Welding Wire; Hotel Cleveland
4:30 P.M. Lecture Course; Physical Testing; Auditorium
8:00 P.M. Lecture Course; Metallurgical X-Rays; Public Auditorium
10:00 P.M. National Metal Exposition closes

Wednesday, Oct. 21, 1936

9:30 A.M. A.S.M. Annual Meeting and Campbell Memorial Lecture; Hotel Statler
9:30 A.M. W.A. Session on Munitions and Military Equipment; Hotel Cleveland
9:45 A.M. A.W.S. Session on Brazing and Hard Surfacing; Hotel Cleveland
12:00 M. National Metal Exposition opens; Auditorium
12:30 P.M. Alumni Luncheons; Hotels Cleveland and Statler
2:00 P.M. A.S.M. Session on Steel Making; Auditorium
2:00 P.M. A.I.M.E. Simultaneous Sessions on Constitution of Alloy Systems and X-Ray Metallography; Auditorium
2:00 P.M. W.A. Session on Wire Drawing; Hotel Cleveland
2:00 P.M. A.W.S. on Non-Ferrous Welding; Hotel Cleveland
4:30 P.M. Lecture Course; Physical Testing; Auditorium
6:30 P.M. A.I.M.E. Institute of Metals and Iron and Steel Division Annual Dinner; Hotel Statler
7:00 P.M. W.A. Informal Dinner; Mayfair
8:00 P.M. Lecture on X-Ray Analysis; Public Auditorium
10:00 P.M. National Metal Exposition closes

Thursday, Oct. 22, 1936

9:30 A.M. A.S.M. Symposium on Plastic Working of Metals; Hotel Statler
9:30 A.M. A.I.M.E. Round-Table Discussion of Physical Testing; Hotel Statler
9:30 A.M. W.A. Session on Copper Wire and Cable; Hotel Cleveland
9:45 A.M. A.W.S. and A.S.M.E. Session on Welding Practice; Hotel Cleveland
10:00 A.M. A.S.M. Session on X-Ray Studies; Hotel Statler
12:00 M. National Metal Exposition opens; Public Auditorium
2:00 P.M. A.S.M. Symposium on Plastic Working of Metals; Public Auditorium
2:00 P.M. A.S.M. Session (simultaneous with above) on Carbon Steels; Public Auditorium
2:00 P.M. A.I.M.E. Round-Table Discussion on Impact and Bend Tests; Statler
2:00 P.M. A.W.S. and A.S.M.E. Joint Session on Welding in Machinery Construction; Hotel Cleveland
2:00 P.M. W.A. Session on Tungsten Carbide Dies; Hotel Cleveland
4:30 P.M. Lecture Course; Physical Testing; Public Auditorium
6:00 P.M. Metal Exposition closes
7:00 P.M. A.S.M. Banquet; Hotel Statler
7:00 P.M. A.W.S. Dinner Dance and Entertainment; Hotel Cleveland

Friday, Oct. 23, 1936

9:30 A.M. A.W.S. and A.S.M.E (jointly) Welding Practice Symposium on Welding of Copper, Nickel and Aluminum Alloys; Hotel Cleveland
10:00 A.M. A.S.M. Symposium on Plastic Working of Metals; Hotel Statler
10:00 A.M. A.S.M. Session (simultaneous with above) on Performance of Steel at Room and High Temperatures; Statler
12:00 M. National Metal Exposition opens; Public Auditorium
2:00 P.M. A.S.M. Symposium on Plastic Working of Metals; Hotel Statler
2:00 P.M. A.S.M. Session (simultaneous with above) on Endurance of Metals; Hotel Statler
2:00 P.M. A.W.S. and A.S.M.E. Session on Welding Practice; Hotel Cleveland
4:30 P.M. Lecture Course; Physical Testing; Hotel Statler
10:00 P.M. National Metal Exposition ends

TECHNICAL MEETINGS

Monday

Morning: Be on hand early, for the opening gun is at 10:00 A. M.

Cast iron experts Schwartz, Johnson and Junge tell how certain metallic elements retard **graphitization**

As a metallurgist in the automotive industry for many years, C. F. Smart has had plenty of opportunity to keep in touch with the latest developments in **cadmium alloys for bearings**

Gases in metals are discussed by W. R. Ham, who gives some new data on diffusion of hydrogen through nickel and iron

Movies too in the morning — Professor Zavarine from M.I.T. has some pictures taken with an unbelievably high-speed lens showing what happens when hot steel is plunged into a **quenching** medium

P. M.: Two Simultaneous Sessions

R. J. Cowan of Surface Combustion Corp. hopes that some of his investigations on continuous **gas carburizing** will result in a vigorous discussion of this very live subject

A new method of heat treating **(surface hardening)** by induced electric currents is sure to attract attention when demonstrated at the Exposition as well as when W. A. Tran and W. E. Benninghoff tell about it at the technical session

With the recent appearance of new and improved strip mills, a paper by N. P. Goss and T. B. Bechtel on continuous heat treatment of **cold-rolled strip** is very timely

The long-neglected field of **titanium as an alloying element** is cultivated by Joseph A. Duma and R. E. Bannon who tell what it will do when added to certain cast metals, and to 18% chromium steel

More light on hydrogen as the cause of **flakes in forgings** — a subject much discussed in "Metal Progress" — is produced by R. E. Cramer

Tuesday

Morning

Investigating the effect . . . .

A somewhat different method of approach was used by Zimmerman, Aborn and Bain in investigating the **effect** of **vanadium** on hardening properties of eutectoid steel

Experiments by G. R. Brophy and E. R. Parker of General Electric Co. support Bain's contention that traces of aluminum in solution do not cause **abnormality** in steel

Harry McQuaid is continuing his research on **aluminum in steel,** some results of which were reported last year in the Campbell Memorial Lecture. This paper tells about the effect of aluminum on carbide formation and solution

Afternoon Session

Because correctly designed machines should not fail when subjected to **repeated stress** but sometimes do, H. B. Wishart and S. W. Lyon are finding out a little more about the question of overload

Krivobok and Lincoln have a contribution on the physical properties of austentic **stainless steels.** They are mostly concerned with advantages of this or that variation in composition in **cold worked** sheet

Carnegie Tech's Barrett, Ansel and Mehl have been studying the phenomena of **slip, twinning and cleavage** and the plasticity of iron and silicon ferrite

Small changes in dimension while even the best tool **steels** are being heat treated is a problem that Ainar Ameen has investigated and now reports upon

Lectures On Both Monday and Tuesday

Lectures will be given by H. D. Churchill on **The Physical Testing of Metals** at 4:30 P.M. and by K. R. Van Horn at 8 o'clock on **Radiography and X-Ray Analysis** in Public Auditorium

TECHNICAL MEETINGS

Wednesday

Campbell Lecture in the Morning

All members are invited to the **annual** meeting of the Society. Newly-elected officers will be inducted, reports of Society activities will be presented, and some highly active Chapter will r e c e i v e the **President's Bell**

All this is but brief preliminary to the Campbell Memorial Lecture. There is no competing attraction. James P. Gill, metallurgist for Vanadium-Alloys Steel Co. and authority on **alloy and tool steels,** has the honor this year

Luncheons

Alumni of six universities will meet at separate luncheons. Find your own group; don't miss this "get-to-gether"!

Melting Session in Afternoon

Magnetic p r o p e r t i e s of slag are indicative of other more important characteristics. B. A. Rogers and K. O. Stamm of the Bureau of Mines point the way to d e t a i l e d studies of this question

Many years of research and investigation have gone into the preparation of Earnshaw Cook's detailed paper on **openhearth slag control**

G. T. Motok, in Republic's metallurgical department, has found in **gas analysis** a new tool for the control of quality steel making. His is an interesting and complicated piece of apparatus, worthy of study

John Chipman and Ta Li have delved into the realm of physical chemistry to learn something more about the control of **sulphur in liquid steel**

Lectures; Afternoon and Evening

The subject of hardness testing is attacked by Prof. Churchill from all angles in his lecture at 4:30. Impact also receives attention

Dr. Van Horn finishes his lecture series this evening at 8:00 with a practical discussion of industrial applications of X-ray diffraction analysis

Thursday

TODAY AND TOMORROW you will need a split personality, for the Symposium on Plastic Working of Metals (see next page) will hold simultaneous sessions with those below

Morning Meeting No. 1

By means of X-ray diffraction studies on **iron-nickel strip,** D. McLachlan and Wheeler P. Davey study the **fragmentation** of crystals **during cold rolling,** both at the surface and in deep seated regions. (If you attended Van Horn's evening lectures you will have a better chance to u n d e r s t a n d this one!)

Find out what Charles S. Barrett thinks about the practicability of applying X-ray diffraction methods to the study of **fatigue in metals**

Ever since Hooke's law was formulated in the 17th century men have speculated on the phenomenon of **distortion in metals.** Clark and Beckwith at University of Illinois attack the problem with X-rays

Afternoon Meeting No. 1

R e s u l t s reported by W. H. Wills should be very helpful in the design and **heat treatment of tools** made of high carbon, high chromium steel

Metallographers will welcome B. L. McCarthy, his paper on boundary attack. It also has definite application to the problem of brittleness in wire after pickling or plating

An excellent example of the c o r r e l a t i o n of laboratory tests to practical usefulness is contained in what H. B. Knowlton has to say on p h y s i c a l properties of steels for **axle shafts**

Afternoon Lecture at 4:30

One whole lecture in Professor C h u r c h i l l's course is devoted to fatigue testing — a subject that well warrants this much attention

Dinner at Seven

Life really begins today at 6:30 in the well-known preliminaries to the **annual Banquet.** The Exposition — everything — closes at 6 o'clock so there are no counter-attractions. Good food, good friends, good and short speeches, some medals for good metallurgists

TECHNICAL MEETINGS

Friday

Morning Meeting No. 1

Valuable indeed should be a method by E. J. Janitzky for converting **elongation** data from one form or size of test piece to the standard 2-in. gage length most generally used

An opportunity to get acquainted with newly elected trustee O. W. Ellis is offered when he presents the results of tests comparing the **forgeability** of certain low alloy steels to that of carbon steel

Some Notes on Cold Drawn Wire

White, Clark and Wilson — names well known to students of the **phenomenon of creep** — tell about tests to determine stress-time for fracture curves for carbon steels at high temperature

Afternoon Meeting No. 1

Press fitted members greatly reduce the **fatigue strength of axles**, according to some practical investigations made by Buckwalter and Horger at Timken Steel & Tube Co.

A. L. Boegehold has found an answer to the question of why the endurance of **gear steels in operation** is lower than fatigue tests would indicate

The third paper on this session will be the first publication in this country of Erich Fetz, native of Germany and at present metallurgist for Wilbur B. Driver Co. It is a study of cold work, dealing with the **changes in nickel wire** at high temperature

Afternoon Lecture

At 4:30 in Public Auditorium Harry D. Churchill of the Faculty of Case School of Applied Science will complete his course of lectures on the Physical Testing of Metals. It has already been tried out on the Cleveland Chapter, and found to be good. **But** — to attend you must register

Some Factors Affecting Cold Rolling

Symposium on the Working of Metals

FOUR SESSIONS (two on Thursday and two on Friday) will be devoted to a well-organized consideration of all the details of this subject. Consult the official program for a time-table for the particular topics

Fundamentals

First A. V. de Forest will give a comprehensive discussion of the **laws and fundamentals** of plastic deformation, considered as one phenomenon of physics

Properties of Metals

Turning then to the way these laws are applied to **metals** comes this series of papers: Plastic deformation of **single crystals**, by S. L. Hoyt . . . . **Creep**, or slow extension under load, and its engineering significance, by C. L. Clark, A. E. White and J. J. Kanter . . . . **Damping**, or the absorption of vibratory stress, by G. R. Brophy . . . . **Hardening** due to plastic flow, by M. F. Sayre . . . . Plastic flow under **shock**, by O. W. Ellis . . . . **Recrystallization** in worked metal, by N. P. Goss

Hot Forming Processes

Broadly speaking, these principles apply either to the **hot working** or the cold working of metals. The most ancient of these is **hammer forging**, discussed by Adam Steever . . . . More recently developed **presses** are discussed by J. H. Friedman . . . . **Extrusion** (still more recent) by D. K. Crampton

Cold Working Processes

Cold rolling of sheet and strip is discussed in the light of the fundamentals by Anson Hayes and R. S. Burns . . . . Factors making for **deep drawing stock** are studied by Joseph Winlock and R. W. E. Leiter . . . . **Cold drawn bars**, by J. E. Beck . . . . **Cold heading** (manufacture of fasteners) by R. H. Smith . . . . Drawing of thin-walled **seamless tube**, by Horace Knerr . . . . Expansion and strengthening of large cylinders (**autofrettage**), by N. E. Woldman

COOPERATING SOCIETIES

American Institute of Mining and Metallurgical Engineers

Tuesday, Oct. 20

10:00 A.M.—Meeting A: Aging in Silver-Copper Alloys, by Morris Cohen . . . . Age Hardening of Aluminum Alloys, by W. L. Fink and Dana Smith . . . . Precipitation Hardening and Double Aging, by R. H. Harrington.

10:00 A.M.—Meeting B: Recovery of Fine Flue Dust, by T. B. Counselman . . . . Improvement of Southern Pig Iron, by J. M. Hassler . . . . Blast Furnace Operation and Refractories, by R. A. Lindgren . . . . Raw Materials for French Blast Furnaces, by Francois Clerf.

2:00 P.M.—Life of Ingot Molds, by W. J. Reagan . . . . Open-hearth Practice . . . . Resume of Reports of British Heterogeneity Committee, by R. C. Good.

Wednesday, Oct. 21

2:00 P.M.—Meeting A: Solubility of Certain Elements in Copper, by J. C. Mertz and C. H. Mathewson . . . . Equilibrium in the Ni-Sn System, by William Mikulas, Lars Thomassen and Clair Upthegrove . . . . Equilibrium in the Al-Mg-Zn System, by W. Fink and L. A. Willey . . . . Constituents of the Cu-Zn Alloys, by J. L. Rodda.

2:00 P.M.—Meeting B: Preferred Orientation in Soft Steel, by M. Gensamer and P. A. Vukmanic . . . . Preferred Orientations Cold-Rolled Sheet Steel, by M. Gensamer and B. Lustman . . . . The Parameter of the Gamma Iron Lattice, by C. Nusbaum and H. A. Schwartz . . . . Constitution of Fe-Si System, by E. R. Jette and E. S. Greiner.

6:30 P.M.—Dinner, Institute of Metals and Iron and Steel Divisions. Address on Metallurgical Reminiscences, by Albert Sauveur.

Thursday, Oct. 22

Round-Table Discussion of Physical Tests and Their Significance. Morning meeting on tensile testing . . . Afternoon meeting on impact and bend.

Heat Treatment of Aluminum

American Welding Society

Thursday and Friday meetings arranged jointly with

American Society of Mechanical Engineers

Monday, Oct. 19

2:00 P.M.—Fundamentals of Metallurgy of Welding, by E. S. Davenport and R. H. Aborn . . . . Multi-Layer Oxy-Acetylene Pipe Welding, by R. M. Rooke, F. C. Saacke and A. N. Kugler . . . . High speed motion picture of the welding processes.

Tuesday, Oct. 20

9:45 A.M.—Heating by the Proximity Effect, by Edward Bennett . . . . Non-Destructive Testing of Welds, by W. B. Kouwenhoven . . . . Impact Tests of Frigid Welds, by Otto Henry.

2:00 P.M.—Characteristics of a Universal Welding Generator, by N. F. Ward . . . Welding Beam-Column Connections, by Inge Lyse . . . . Circuit Characteristics and Arc Stability, by S. C. Osborne . . . . Structural Brackets, by C. D. Jensen.

7:30 P.M.—Conference and meeting of Fundamental Research Committee, Bureau of Welding Research and Engineering Foundation.

Wednesday, Oct. 21

9:45 A.M.—Brazing With Silver Solders, by R. H. Leach . . . . Design Control for Welded Piping Systems, by T. W. Greene . . . . Principles of Surfacing by Welding, by E. W. P. Smith . . . . Resistance Welding of Ferrous and Non-Ferrous Sheet Metals, by E. I. Larsen.

2:00 P.M.—Procedures for Control of Welding Parts, by G. H. Moore, Jr. . . . . Welding Copper and Its Alloys—A Review of the Literature, by Ira T. Hook . . . . Resistance Welding of Dissimilar Metals, by R. T. Gillette . . . . Thermit Welding, by J. H. Deppeler . . . . An Exploration of a Modern Metallic Arc, by L. J. Larson.

Thursday, Oct. 22

9:45 A.M.—Welding Design, by C. H. Jennings . . . . Alloy Steels and their Weldability, by A. B. Kinzel . . . . Welding of Alloy Steels, by W. L. Warner.

2:00 P.M.—Rolled Steel in Machine Construction, by H. G. Marsh . . . . Welding Heavy Machinery and Equipment, by C. A. Wills and F. L. Lindemuth . . . . Modern Resistance Welding Developments, by A. E. Hackett.

7:00 P.M.—Dinner dance.

Friday, Oct. 23

9:30 A.M.—Application of Copper Alloy Welding, by I. T. Hook . . . . Welding of Monel Metal and Pure Nickel, by F. A. Flocke . . . . Welding the Aluminum Alloys, by G. O. Hoglund.

2:00 P.M.—Magnaflux Inspection of Large Welded Vessels . . . . Radiographic Inspection of Refinery Equipment, by H. R. Isenburger . . . . Castings vs. Welding, by J. L. Brown.

The Wire Association

Monday, Oct. 19

3:30 P.M.—Business meeting.

Tuesday, Oct. 20

9:30 A.M.—Cleaning Houses in the Wire Industry, by A. F. Anjeskey . . . . Atmospheres and Furnaces in the Wire Industry, by H. M. Heyn.

2:00 P.M.—Materials for Springs, by J. W. Rockefeller, Jr. . . . . Welding Wire, by R. Notvest . . . Making of Stainless Steel, sound motion picture.

Wednesday, Oct. 21

9:30 A.M.—Research as Applied to Manufacturing, by C. W. Meyers . . . . Development of Types of Military Equipment, by Frank W. Bullock, U. S. A. . . . . Signal Communications Within the Infantry Regiment, sound motion picture.

2:00 P.M.—Plastic Deformation in Wire Drawing, by B. L. McCarthy.

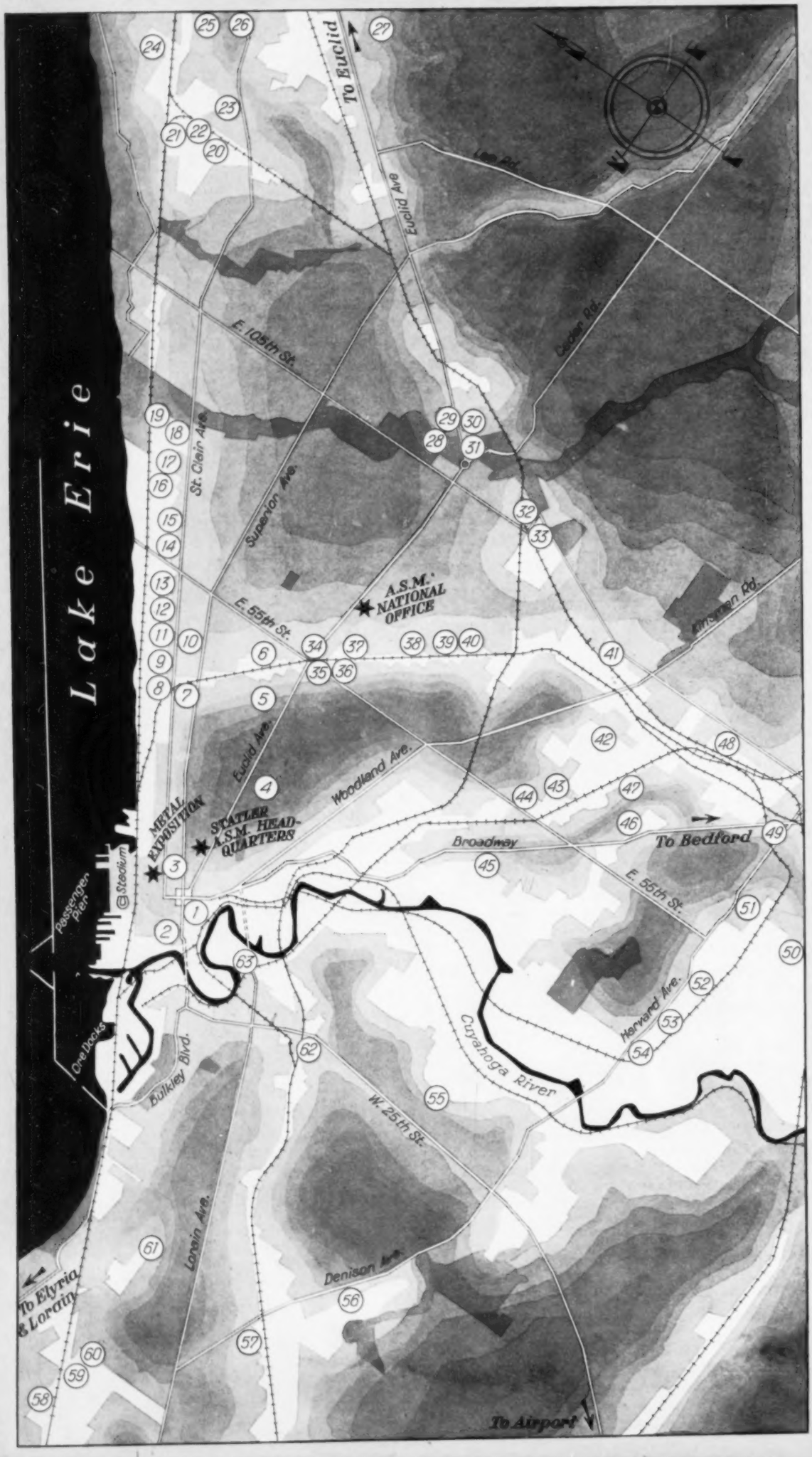
7:00 P.M.—Informal Dinner.

Thursday, Oct. 22

9:30 A.M.—Endurance Tough-Pitch and Oxygen-Free Copper Wire, by J. N. Kenyon . . . . Vacuum Lead Sheath for Power Cable, by R. W. Atkinson . . . . Power for Cascade Drawing of Copper, by Paul M. Mueller . . . . Tactical Employment of Anti-Aircraft Artillery, sound motion picture.

2:00 P.M.—Tungsten Carbide, by A. R. Zapp . . . . Method of Handling the Die Room, by K. R. Beardslee.

THE METAL INDUSTRY OF CLEVELAND



48 Allyne-Ryan Foundry Co.
54 Aluminum Co. of America
14 American Gas Assoc. (Res. Lab.)
American Steel & Wire Co.:
53 Cuyahoga Works
49 Newburgh Works
25 Apex Electrical Mfg. Co.
28 Art Museum
10 W. S. Bidle Co.
5 Brush Laboratories Co.
62 Case Hardening Service Co.
31 Case School of Applied Science
36 Chandler & Price Co.
17 Cleveland Graphite Bronze Co.
42 Cleveland Hardware & Forging Co.
9 Cleveland Punch & Shear Co.
11 Cleveland Twist Drill Co.
Cleveland Wire Spring Co.:
8 Spring Division
52 Sheet Metal Plant
57 Crucible Steel Casting Co.
24 Eaton Mfg. Co.
32 Fairmount Tool & Forging Co.
4 Fenn College
43 Ferro Machine & Foundry Co.
23 Fisher Body Corp.
47 Fulton Foundry & Machine Co.
General Electric Co.:
27 Nela Park
6 Carboloy Division
46 Grabler Mfg. Co.
3 Hollenden Hotel
12 Lake City Malleable Co.
13 Lakeside Steel Improvement Co.
61 Lamson & Sessions Co.
21 Lincoln Electric Co.
59 Midland Steel Products Co.
22 National Acme Co.
58 National Carbon Co.
33 Nat'l Malleable & Steel Castings Co.
39 National Screw & Mfg. Co.
50 National Smelting Co.
51 Ohio Crankshaft Co.
26 Ohio Gear & Machine Co.
55 Otis Steel Co.
19 Park Drop Forge Co.
34 Pennsylvania RR. (E. 55th St. Sta.)
40 Perfection Stove Co.
Republic Steel Corp.:
45 Corrigan-McKinney Plant
20 Steel & Tubes, Inc.
63 Upson Bolt & Nut Co.
29 Severance Hall
15 Steel Improvement & Forge Co.
1 Terminal Tower & Cleveland Hotel
37 Thompson Products, Inc.
44 Truscon Steel Co.
7 W. S. Tyler Co.
56 United Screw & Bolt Corp.
41 Vichek Tool Co.
35 Wanner & Swasey Co.
2 Weatherhead Co.
38 Wellman Engineering Co.
16 West Steel Casting Co.
30 Western Reserve University
18 White Motor Co.
60 Winton Engine Mfg. Corp.

Euclid

Addressograph-Multigraph Corp.
Ajax Mfg. Co.
Chase Brass & Copper Co.
Cleveland Tractor Co.
Euclid Road Machinery Co.
General Electric Co., Wire Works
Geometric Stamping Co.

Bedford

Cuyahoga Steel & Wire Co.

Elyria

Electro Alloys Co.
Western Automatic Mach. Screw

Lorain

National Tube Co.

SEE CLEVELAND WHILE YOU ARE HERE

THE MAP at the left has been prepared to aid in plant visitations. (Consult official program for arrangements.) It will inform you, for instance, that Cleveland Tractor Co. and Addressograph-Multigraph Corp. are both in Euclid and can be seen at one trip, or that Cleveland Graphite Bronze and Steel Improvement and Forge Co. are near each other. On the other hand do not make appointments at National Acme Co. and Corrigan-McKinney plant of Republic Steel Corp within 30 min. of each other.

Two automobile tours, recommended for sight-seeing, are below and on the next page.

Tour West to Rocky River Reservation

0.0 Start north on East 12th St. from side entrance of Statler Hotel. At second stop light turn left on Superior. Follow Route 6 9.0 miles to Rocky River.

0.2 Pass St. John's Cathedral on Superior at East 9th St.

0.4 Federal Reserve Bldg., Plain Dealer Bldg., Main Library, Federal Bldg. on right. (The Mall is behind these buildings.)

0.6 Straight through Public Square. Cleveland College and Old Stone Church on right; Soldiers' and Sailors' Monument and Terminal Group of buildings on left.

0.8 New Post Office some distance at left; wholesale district on right.

1.0 Cross High Level bridge over Cuyahoga River. Harbor entrance at right; "Flats" under bridge.

1.5 Turn right at first ramp to Bulkley Blvd., still following Route 6.

1.7 Edgewater Terrace, low-cost housing project on right.

1.9 Filtration plant on right.

2.0 Ore docks at right, distance; nearby: American Shipbuilding Co. and drydocks.

4.2 Cross West Blvd. onto Lake Ave.

5.1 Leave Cleveland; enter Lakewood. Christian Science Church on left.

5.5 Lake Shore Hotel at right.

6.6 Lakewood Park on right.

8.0 Follow car-line on West Clifton Blvd. as far as bridge. Right: Clifton Park section.

★ 9.0 Leave Route 6; go straight across intersection and down hill into Rocky River Reservation of Metropolitan Park System. (Routes 2 and 6 lead to Lorain across Rocky River bridge; Route 20 to Elyria.) Across bridge are Westlake Hotel and Cleveland Yacht Club.

9.3 Turn left and cross river.

9.9 Pass under Hilliard Road bridge.

10.3 Turn left and cross river.

12.9 Pass under new Lorain Ave. bridge, a prize-winner as an artistic design.

13.1 Take right fork. Rocky River Golf Course No. 2 to the left.

13.7 Cleveland Archery Club at right.

14.0 Jog to the right to main road, then left. Rocky River golf links No. 1 at right.

14.9 Picnic grounds.

16.4 Pass under Brook Park bridge.

18.3 Turn right on cross-road. Little Cedar Point.

18.4 Turn left just before coming to bridge.

21.4 Turn left.

21.9 Turn left over bridge and then turn right; entering Berea.

22.5 Right on Route 237 into center of town.

★ 22.7 Turn left at first stop light onto East Bridge St. Go one block and turn left on Seminary Road.

23.2 Turn left at dead end, then right at stop light onto Front St. and Route 237. Baldwin-Wallace College at right.

24.4 Enter Brook Park.

26.0 Cleveland Municipal Airport at left.

26.7 Right on Brook Park Road and Route 17.

30.8 Road at right leads to Big Creek Reservation of Metropolitan Park System.

32.1 Turn left on Pearl Road, Route 42 and Temporary Route 3.

34.4 Brookside Park and Zoo at left.

34.8 Cross Denison Ave. East on Denison Ave. (which becomes Harvard Ave.) are Aluminum Co. of America and Cuyahoga Works of American Steel & Wire Co.

35.2 Pass Scranton Road. Right on Scranton leads to Flats (heavy industries).

36.2 Cross Clark Ave. Clark Ave. bridge to right.

★ 37.2 Turn right on Lorain Ave. West Side Market district.

37.4 Cross Lorain-Central bridge. Upson Nut Works at left.

★ 38.3 Turn left at end of bridge on Ontario. Fire Department Exchange at right.

38.4 Central Market at right, Scranton Road at left.

38.7 Terminal Group of buildings at left.

☆ 38.8 Turn right on Euclid Ave., through retail shopping center.

★ 39.3 Turn left on East 12th St. to end tour.

Tour East to Industrial and Residential Sections

0.0 Start east on Euclid Ave. from Statler. Follow Route 20 4.2 miles to Ford Road.

0.5 Trinity Cathedral (Episcopal) on right.

0.7 Cleveland Institute of Music and Museum of Natural History on left.

0.9 First Methodist Episcopal Church on right.

1.0 John Huntington Polytechnic Institute, typical of old mansions of millionaires' row in the 1890's.

1.1 Masonic Auditorium on left.

1.3 University Club on left. First Rockefeller mansion at S. W. corner of East 40th St.

2.1 Dunham Tavern, one of Cleveland's oldest buildings, on left.

2.3 A.S.M. National Office on right, corner of East 71st St.

3.6 Cross East 105th St.; Shopping and business district.

★ 3.8 107th St. and University Circle; bear left, following Route 20.

3.9 Wade Park, Cleveland Art Museum, and "Holy Inkwell" (copper-domed Methodist church) on left.

4.0 Severance Hall, home of Cleveland Symphony Orchestra on left. Case School of Applied Science and Western Reserve University on right.

4.1 Church of the Covenant on left, University Hospitals on right.

★ 4.2 Turn left on Ford Road.

4.3 Flora Stone Mather College for Women.

4.5 At dead end turn right on Magnolia Drive and circle to left. Fine old residential district.

5.2 Turn left on East 105th St.

★ 5.4 At first traffic light turn right into Rockefeller Park. Follow main road through park.

6.6 Open air theater to right and Shakespearean Gardens on high ground above.

7.8 Turn right at Lake Erie onto Lake Shore Blvd., follow Temporary Route 2 to Coit Road.

8.1 Enter Bratenahl, lake-shore mansions.

★ 10.1 Turn right on Coit Road.

10.3 Lincoln Electric Co. on right.

10.4 National Acme Co. on right.

10.6 Fisher Body Corp. on left.

★ 11.0 Turn left on St. Clair Ave.

★ 11.4 Turn right on Ivanhoe Rd. (left fork; right is East 152nd St.)

11.8 Atlas Bolt & Screw Co. on right. Also Foster-Wheeler Corp.

★ 12.2 Turn right on Euclid Ave.

12.3 Turn left on Nela.

12.5 Enter gates into Nela Park and follow white line on pavement to Noble Road. Nela Park is the General Electric Institute for the study of lights and lighting.

12.9 Turn left on Noble Road.

★ 13.2 Turn right on Nelaview (first of the two traffic lights).

13.8 Cross Taylor Rd.; continue on Glynn Road.

14.0 Turn left on Mt. Vernon, then right on Brewster Road. Rockefeller high-cost housing project.

14.5 Turn left on Lee Road. Pass through center of Rockefeller estate, now being subdivided.

★ 15.8 Turn right on Euclid Heights Blvd.

★ 16.5 Turn left into Coventry Road; fine residential district.

16.8 Turn right on East Overlook Road.

17.1 Take left fork on Norfolk.

17.5 Turn right on Cedar Road.

★ 17.6 Sharp left up hill on Fairmount Blvd.

★ 18.5 Leave car tracks and take right fork on Coventry.

19.3 Turn right on Shaker Blvd. (Left leads out into Shaker Heights, now the most popular residential suburb.)

19.5 Shaker Square, straight through.

20.4 St. Luke's Hospital on right.

20.5 Turn right on East Blvd. and bear right; following boulevard bear left at 20.7.

21.4 Filtration Plant and Reservoir at left.

21.6 Turn right out of ravine on Chestnut Hills Drive.

22.0 End of Chestnut Hills Drive; turn left on Harcourt Drive.

22.2 Turn sharp left on Cedar Road, down Cedar Glen (main traffic way).

22.7 Take right fork at foot of hill. Case School of Applied Science and Western Reserve University on right.

★ 22.8 Bear left onto Carnegie Ave.

23.0 Cleveland Club on left.

23.8 The Play House on East 86th St. to right.

24.6 Thompson Products at left.

24.9 Warner & Swasey Co. on right; Chandler & Price at left.

★ 25.6 Turn left on East 36th St.

25.7 Turn right on Cedar Ave.

25.9 Cedar-Central Apartments, Uncle Sam's low-cost housing project.

★ 26.3 Turn right on East 22nd St. Charity Hospital at left.

★ 26.5 Turn left on Euclid Ave.

★ 27.1 Trip ends at Statler Hotel.

METAL EXPOSITION

Alphabetical list of EXHIBITORS

Acme Steel Co., Booth M-9. Colored cold rolled strip steel.
Aetna Gases, Inc., Booth N-46. Gases.
Air Reduction Sales Co., Booth G-7. Welding and cutting torches, brazing and hard facing apparatus.
Ajax Electric Co., Booth A-3. Electric heat treating furnaces.
Ajax Electrothermic Corp., Booth A-3. High frequency furnaces.
Allegheny Steel Co., Booth C-22. Stainless steels, sheets, bars, plates, strip, tubing, wire, rivets.
Edgar Allen Steel Co., Inc., Booth D-22. Tool and die steels.
Alox Corp., Booth N-61. Rust preventatives.
Aluminum Co. of America, Booth I-23. Aluminum alloys.
American Brass Co., Booth C-21. Copper alloys.
American Bridge Co., Booth C-15. (See United States Steel Corp.)
American Car & Foundry Co., Booth E-32. Electric bar heaters, forging heaters, rivet heaters.
American Crucible Co., Booth O-15 (one half). Crucibles and retorts, graphite products.
American Cyanamid & Chemical Corp., Booth N-47. Case hardening compounds, chemicals.
American Electric Furnace Co., Booth I-4. Electric furnaces.
American Foundry Equipment Co., Booth M-48. Cleaning and descaling equipment.
American Gas Association, Industrial Gas Section. Gas equipment.
American Gas Furnace Co., Industrial Gas Section. Heat treating furnaces.
American Institute of Mining & Metallurgical Engineers, Booth P-19. Educational exhibit.
American Machine & Foundry Co., Booth M-47. Machinery, cast parts.
American Machine & Metals Mfg. Co., Booth B-19. Hardness testing machines.
American Machinist, Booth N-53. Publications.
American Metal Market, Booth L-47 (left half). Publications.
American Rolling Mill Co., Booth L-59. Stainless steels, enameling iron, sheets and plates.
American Sheet & Tin Plate Co., Booth C-15. (See U. S. Steel Corporation.)
American Society for Metals, Booth P-7. Educational exhibit.
American Steel & Wire Co., Booth C-15. (See United States Steel Corp.)
American Welding Society, Booth N-60. Educational exhibit.
Ampco Metal, Inc., Booth A-19. High strength non-ferrous alloys.
Anderson & Sons, Booth N-51 (west half). Etched and lithographed metal products.
Armstrong-Blum Mfg. Co., Booth P-28. Metal sawing machines, hacksaws, tapping machines.
Armstrong Cork Co., Booth L-11. Insulating materials.
Automatic Temperature Control Co., Inc., Booth L-9. Temperature control systems, control valves for air, gas, water, oil and steam.
Automotive Industries, Booth O-10. Publications.

Babcock & Wilcox Co., Booth N-18. Refractories.
Baldwin-Southwark Corp., Booth P-15. Testing machines.
Bartlett-Hayward Co., Booth N-2. Bronze alloy products.
Bastian Blessing Co., Booth L-19. Oxy-acetylene welding and cutting equipment.
Bausch & Lomb Optical Co., Booth D-23. Optical instruments for metallography and spectrography.
Bell & Gossett Co., Booth G-23. Case hardening compounds, heat treating supplies.
Bethlehem Steel Co., Booth F-15. Carbon and alloy steels.
G. S. Blakeslee & Co., Booth L-51. Cleaning and degreasing machines.
Bliss & Laughlin, Inc., Booth F-20. Cold finished bar steels.

Botfield Refractories Co., Booth N-49. Refractories.
Bristol Co., Booth L-15. Pyrometers, temperature control equipment.
Brown Instrument Co., Booth N-22. Indicating and recording instruments, automatic control equipment.
A. I. Buehler, Booth N-10. Metallographic equipment.
Bullard Dunn Process Div., The Bullard Co., Booth M-54. Cleaning and descaling equipment.
Burdett Mfg. Co., Industrial Gas Section. Gas burning equipment.
Calorizing Co., Booth L-18. Heat resisting alloys and equipment.
Carboloy Company, Inc., Booth A-20. Cemented carbide tools.
Carborundum Co., Booth O-38. Abrasives, grinding and cutting wheels, refractory products.
Carnegie-Illinois Steel Corp., Booth C-15. (See United States Steel Corp.)
Case Hardening Service Co., Booth G-23. Carburizing compounds, heat treating materials.
Chapman Valve Mfg. Co., Booth O-18. Chapmanizing process; steel valves.
Chemical Rubber Co., Booth M-51. Laboratory equipment.
Chilton Co., Booths O-10 and O-48. Publications.
Climax Molybdenum Co., Booth F-3. Molybdenum steels and irons.
Colmonoy Co., Booth N-46. Hard facing materials, cutting tools.
Columbia Steel Co., Booth C-15. (See United States Steel Corp.)
Columbia Tool Steel Co., Booth H-32. High speed and tool steels.
Continental Industrial Engineers, Inc., Industrial Gas Section. Heat treating systems.
Continental Machine Specialties, Inc., Booth P-11. Precision filing and sawing equipment.
Crown Rheostat & Supply Co., Booth L-46. Plating and polishing tools.
Cyclops Fence Co., Booth C-15. (See United States Steel Corp.)
Cyclops Steel Co., Booth G-32. Tool steels, stainless and specialty steels.
Dayton Rogers Mfg. Co., Booth E-3. Metal stampings.
A. P. De Sanno & Son, Booth L-5. Abrasive cutting equipment.
Despatch Oven Co., Industrial Gas Section. Gas heat treating furnaces.
Detroit Testing Machine Co., Booth N-54. Physical testing apparatus.
De Walt Products Corp., Booth L-53. Metal cutting machines.
Joseph Dixon Crucible Co., Booth I-24. Stoppers, nozzles and sleeves.
Dow Chemical Co., Booth C-27. Magnesium alloy die castings, forgings, rolled sheet and plate, and extruded sections.

POLISHING MACHINE

RING ILLUMINATOR

PANPHOT

MEASURING MICROSCOPE

Leitz

Has Helped Optically to Maintain Progress in Metallurgy

In Booth H-14 at the Cleveland Metal Show we will have on exhibition the latest design Leitz Instruments and Apparatus for precision control of production and deeper research into the grain structures and behavior of metals.

In addition, we will exhibit for the first time the Leitz TYNDALLOMETER, a unique optical instrument for making accurate measurements of dust contents in air without the need of air samples. It's all done by visual observation.

● *Among the other instruments to be exhibited are:*

DILATOMETERS

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MICROSCOPES

High precision Measuring Microscopes for aiding in production control; large and small Micro-Metallograph for observation in darkfield and polarized light; inexpensive Metal Microscopes with Photomicrographic Camera Attachments.

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Leitz PANPHOT, industry's most versatile combination camera and microscope; simple Unit Ma-111 with special new large Ring Illuminator for photographing large objects.

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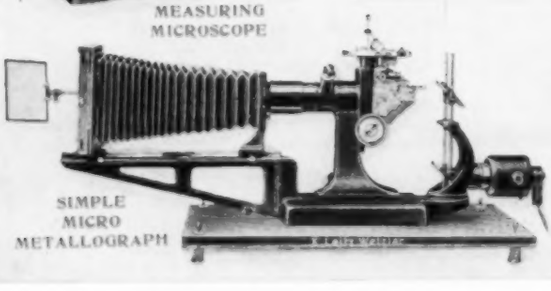
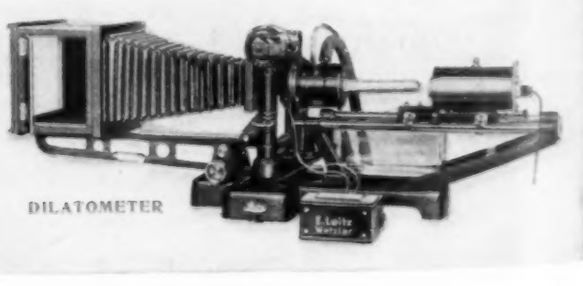


SIMPLE MICRO METALLOGRAPH



DILATOMETER

METAL EXPOSITION

Alphabetical list of EXHIBITORS

Driver-Harris **Co.**, Booth G-21. Heat and corrosion resisting alloys.

E. I. du Pont de Nemours & **Co.**, Booth C-32. Heat treating salts; sodium; plating chemicals; metal cleaners.

Eclipse Fuel **Engineering Co.**, Industrial Gas Section. Heat treating furnaces and equipment.

Electric Furnace **Co.**, Booth L-21. Heat treating furnaces.

Electro-Alloys **Co.**, Booth M-6. Heat and corrosion resisting alloys.

Electro Metallurgical **Co.**, Booth O-30. Alloy steels and cast irons.

Elevator Supplies **Co.**, Booth O-9. Wire drawing machines.

Ensign-Reynolds, **Inc.**, Industrial Gas Section. Soft metal melting furnaces, soldering furnaces, burners, gas compressors, air blowers.

Firth Sterling Steel **Co.**, Booth D-32. Carbide tools, stainless steel products, wear resistant parts.

J. B. Ford Sales **Co.**, Booth H-22. Metal cleaners, burnishing compounds.

C. A. **Fox**, Booth H-2 (one half). Abrasive cut-off machines.

Foxboro **Co.**, Booth L-1. Measurement and control instruments.

Fulton Foundry & Machine **Co.**, Booth O-33. Meehanite metal, high strength gray iron.

Gas Machinery **Co.**, Industrial Gas Section. Forging furnaces.

Gas Products **Co.**, Booth M-44. Acetylene, oxygen, gases.

Gathmann Engineering **Co.**, Booth C-6. Ingot molds.

General Alloys **Co.**, Booth P-8. Heat and corrosion resisting alloys, furnace parts.

General Electric **Co.**, Booth E-23. Electric furnaces and welding machines.

General Electric X-Ray **Corp.**, Booth E-21. X-ray testing equipment.

Globar Division of Carborundum **Co.**, Booth O-36. High temperature heating elements.

Gogan Machine **Co.**, Booth N-9. Hardness testing machines.

Claud S. Gordon **Co.**, Booth B-18. Pyrometers and accessories.

Grasselli Chemical Co., Inc., Booth E-33. Pickling inhibitors, fluxes, acids, chemicals for plating.

Great Lakes Steel Corp., Booth P-16. Sheet and strip steel, alloy steel.

Grob Brothers, Booth E-2. Die making equipment, saws, filing machines, brazing devices.

Hamilton Steel Co., Booth P-23. Steels.

Handy & Harman, Booth D-27. Brazing alloys and silver solders.

Hardinge Brothers, Booth L-14. Machine tools.

Harnischfeger Corp., Booth L-54. Electric welding equipment and motors.

Hauck Manufacturing Co., Booth N-5. Oil and gas burners, regulating valves.

C. I. Hayes, Inc., Booth G-15. Heat treating furnaces.

Haynes-Stellite Co., Booth O-30. Cutting tools, corrosion resistant castings.

Heat Treating & Forging, Booth N-13. Business papers.

Hevi Duty Electric Co., Booth G-25. Electric heat treating equipment.

Hobart Brothers Co., Booth B-15. Electric arc welding equipment.

A. F. Holden Co., Booth M-18. Heat treating baths.

Hollup Corp., Booth A-15. Electric arc welders, electrodes and equipment.

Charles A. Hones, Inc., Industrial Gas Section. Gas oven furnaces, melting furnaces, soft metal and soldering furnaces, industrial gas burners.

Hoskins Mfg. Co., Booth M-59. Heating element alloys.

E. F. Houghton & Co., Booth I-8. Carburizing compounds; heat treating salts; industrial lubricants; cutting oil; leather belting and packings.

Illinois Testing Laboratories, Inc., Booth N-26. Pyrometers; thermometers; meters.

Industry & Welding, Booth P-24. Publications.

Industrial Press, Booth O-21. Publications.

Ingersoll-Rand Co., Booth N-45. Blowers and compressors.

International Nickel Co., Inc., Booth B-7. Nickel and nickel alloys.

Iron Age, Booth O-48. Publications.

Iron & Steel Publishing Co., Booth O-34. Publications.

C. O. Jelliff Mfg. Co., Booth N-11. Resistance wire, heat resisting alloys.

Johns-Manville Co., Booth N-38. Insulating and refractory materials.

Jones & Laughlin Steel Corp., Booth E-15. Hot and cold rolled steel, tinplate.

J. W. Kelley Co., Booth H-16. Heat treating products, industrial oils.

Kelley-Koett Mfg. Co., Inc., Booth A-18. X-ray apparatus.

C. M. Kemp Mfg. Co., Industrial Gas Section. Gas producers and premixers.

G. N. Krouse, Booth Q-20. Fatique testing machines.

Lakeside Steel Improvement Co., Booth O-22. General heat treating.

La Salle Steel Co., Booth N-50. Steels.

Leeds & Northrup Co., Booth I-15. Heat treating furnaces, pyrometers and controlling instruments.

E. Leitz, Inc., Booth H-14. Photomicrographic apparatus.

Lewis Machine Co., Booth L-10. Wire drawing machines.

Lincoln Electric Co., Booth F-23. Electric welding equipment and supplies.

Lindberg Engineering Co., Booth L-33. Heat treating equipment.

Linde Air Products Co., Booth O-30. Welding and cutting apparatus, welding gases.

Machinery, Booth O-21. Publications.

Macklin Co., Booth C-26. Grinding wheels; cut-off machines.

Magnaflux Corp., Booth N-15. Inspection method and equipment.

Magnetic Analysis Corp., Booth D-4. Magnetic analysis equipment.

Mahr Mfg. Co., Booth N-44. Oil and gas furnaces; burners.

P. R. Mallory & Co., Booth H-26. Welding metals.

(Continued on page 22)

METAL EXPOSITION

Alphabetical list of EXHIBITORS

Manhattan Rubber Mfg. Co., Booth H-2. Abrasive cut-off and finishing wheels.
John A. Manning Paper Co., Inc., Booth M-1. Rope papers, insulation, specialty papers.
Marburg Brothers, Inc., Booth L-50. Cutting tools, gages, pneumatic hammers.
Metal Industry, Booth N-50. Publications.
Metal & Thermit Corp., Booth H-27. Welding electrodes and equipment.
Metals & Alloys, Booth B-2. Magazine.
Metals Coating Co. of America, Booth O-45. Sprayed metal coating equipment.
Michiana Products Corp., Booth N-14. Heat and corrosion resistant alloy castings.
Michigan Steel Casting Co., Booth I-14. Heat, corrosion resisting castings.
Midvale Co., Booth B-14. Carbon and alloy steels.
A. Milne & Co., Booth D-22. Tool and die steels.
Minneapolis-Honeywell Regulator Co., (See Brown Instrument Co.)
Modern Machine Shop, Booth M-14. Magazines.
Molybdenum Corp. of America, Booth O-24. Molybdenum and tungsten alloys.
Monarch Steel Corp., Booth M-55. Cold drawn steels and shafting.
Morse Magneto Clock Co., Booth O-47. Time clocks.
Mullite Refractories Co., Booth O-15. Refractories.
National Cylinder Gas Co., Booth M-44. Oxy-acetylene cutting machines.
National Industrial Publishing Co., Booth O-27. Publications.
National Tube Co., Booth C-15. Tubing.
New Jersey Zinc Co., Booth D-21. Zinc alloys; die castings.
Nickel & Chromium Products Co., Booth L-23. Plating equipment.
North American Mfg. Co., Industrial Gas Section and M-45. Industrial gas burning equipment.
Norton Co., Booths Q-12 and Q-16. Grinding wheels, refractories.
Ohio Crankshaft Co., Booths A-5, A-9, and B-4. Automatically hardened crankshafts.
Tinius Olsen Testing Machine Co., Booth B-8. Testing machines.
Oster Manufacturing Co., Booth D-2. Jigs and fixtures for welding, torch cutting machines, pipe and bolt threading machines.
Page Steel & Wire Division, American Chain Co., Inc., Booth C-23. Welding wire, miscellaneous wire.
Pangborn Corp., Booth P-27. Blast cleaning and dust collecting equipment.
Park Chemical Co., Booth M-11. Heat treating materials, buffing and polishing materials.
Parker-Kalon Corp., Booth I-26. Screws and fastening devices, measuring instruments, gage blocks.
Partlow Corp., Industrial Gas Section. Temperature controls, gas valves, safety pilots.
Henry Pels & Co., Booth Q-24. Cutting and fabricating machines.
Philadelphia Drying Machinery Co., Booth M-46. Heating furnaces, oil burners, gas burners.
Pittsburgh Instrument & Machine Co., Booth G-34. Brinell hardness testing machines.
Product Engineering, Booth N-53. Publications.
Products Finishing, Booth M-14. Publications.
Production Machine Co., Booth Q-23. Polishing, finishing and buffing machines.
Pyrometer Service & Supply Co., Booth B-18. Pyrometers and accessories.
Quigley Co., Inc., Booth L-37. Refractories.
Republic Steel Corp., Booth E-6. Alloy and stainless steels, sheets, bolts and nuts, pig iron, etc.
John A. Roebling's Sons Co., Booth O-12. Wire rope and miscellaneous wire.
Rustless Iron & Steel Corp., Booth L-43. Rustless or stainless steels.
Joseph T. Ryerson & Son, Inc., Booth I-22. Steel and allied products.
The Safety Gas Lighter Co., Booth I-33. Gas lighters, gas ranges, hot water heaters.
Salem Engineering Co., Booth M-10. Furnaces.
George Scherr Co., Inc., Booth D-26. Optical instruments and testing machines.
Scully Steel Products Co., Booth C-15. (See United States Steel Corp.)
Selas Co., Industrial Gas Section. Gas premixers, burners, soldering systems.
Sentry Co., Booth O-25. Hardening furnaces, high temperature tube furnaces.
Spencer Turbine Co., Booth N-34. Turbo compressors, vacuum cleaners.
Steel, Booth Q-4. Publications.
Steel City Testing Laboratory, Booth M-5. Testing machines.
Stoody Co., Booth N-8. Hard facing materials, cutting tools.
D. A. Stuart & Co., Booth L-25. Industrial oils and greases.
Surface Combustion Corp., Industrial Gas Section. Heat treating furnaces, burners, accessories.
Syncro Machine Co., Booth N-1. Wire machinery.
C. J. Tagliabue Mfg. Co., Booth M-15. Indicating, recording and controlling pyrometers.
Tennessee Coal, Iron & Railroad Co., Booth C-15. (See United States Steel Corp.)
Timken Steel & Tube Co., Booth F-33. Alloy steels.
Titanium Alloy Mfg. Co., Booth M-50. Titanium alloys and compounds.
Una Welding, Inc., Booth H-23. Arc welding machines.
Union Carbide Co., Booth O-30. Welding and cutting equipment, ferro-alloys, heat and corrosion resisting alloys.
United States Steel Corp., Booth C-15. Alloy steels, high tensile and stainless steels.
Universal Steel Co., Booth G-32. Tool steels, stainless and specialty steels.
Vanadium Alloys Steel Co., Booth Q-28. Vanadium steel; tool steels.
Vanadium Corp. of America, Booth G-2. Vanadium alloys and compounds.
Victor Saw Works, Inc., Booth F-2. Hack saw blades and machines.
Welding Engineer Publishing Co., Booth M-49. Publications.
Weldit Acetylene Co., Booth M-16. Welding equipment.
Wells Manufacturing Corp., Booth I-2. Metal cutting saws.
Wheelco Instruments Co., Booth I-32. Temperature control instruments.
Wheelock, Lovejoy & Co., Inc., Booth H-21. Alloy steels.
Williams & Co., Booth O-38. Nickel, aluminum, brass and copper, welding electrodes and machines.
Wilson Mechanical Instrument Co., Booth C-25. Rockwell hardness testers.
Wilson Welder & Metals Inc., Booth G-7. Electric welding machines.
Wire Association, Booth N-3. Educational exhibit.
Youngstown Sheet & Tube Co., Booth E-24. Alloy steels.
Carl Zeiss, Inc., Booth C-33. Microscopes and accessories.

Personals

J. C. **Warner**, associate professor of theoretical chemistry, has been appointed associate professor of metallurgy at Carnegie Institute of Technology.

Harold F. **Sprague** ⊜ is a member of the metallurgical department of the Weirton Steel Co.

Edward P. Barrett ⊜ has transferred from the Pittsburgh Station to the Minneapolis Station of the U. S. Bureau of Mines, where he will continue experimental work on blast furnace problems.

Walter P. Benter ⊜ is with Carnegie-Illinois Steel Corp., Pittsburgh District, in the metallurgical department, alloy division.

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John N. Lynn ⊜ is laboratory assistant at the South Metallurgical Laboratory of Republic Steel Corp. in Canton, Ohio.

Donald Ingvoldstad ⊜ is now employed as research engineer at the Bunker Hill lead smelter, Kellogg, Idaho.

Rudolph Furrer has been appointed industrial engineer in the manufacturing department of Allis-Chalmers Mfg. Co., Milwaukee.

Richard Shaw, Jr., ⊜ has resigned from Blaw-Knox to enter the specialty engineering department of the Bristol Co., Waterbury, Conn.

Carl Nygren has been appointed chief engineer of the Michiana Products Corp., Michigan City, Ind.

Frank C. Miller has been appointed manager of sales, Tin Plate Division of Republic Steel Corp. **P. H. Hubbard** and **J. B. DeWolf** have been named assistant managers.

Grover C. Dillman has been inaugurated as president of the Michigan College of Mining and Technology, Houghton, Mich.

J. H. W. Kerston has been appointed sales promotion manager of Pfaltz & Bauer, Inc., New York City.

William Miller, formerly assistant manager of sales of tin mill products for Jones & Laughlin Steel Corp., has been appointed manager of sales of sheet and strip products.

T. G. Baer has been appointed manager of the Buffalo office of the Timken Roller Bearing Co.

C. R. Jernberg, formerly vice-president of the Standard Forgings Co., has joined the Kropp Forge Co., to direct sales in the territory contiguous to Chicago.

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Personal Mention

H. B. Pulsifer has been made director of the laboratory in the Cleveland district for American Steel & Wire Co.

S. E. Sjogren has been appointed district sales manager of the Columbia Tool Steel Co. in the Detroit territory.

Frank W. Kasdorf, Jr. is a sales apprentice for Aluminum Co. of America.

T. L. Joseph has resigned from the Bureau of Mines to become Professor of Metallurgy at the Minnesota School of Mines and Metallurgy.

J. T. Howat has been appointed chief metallurgist and superintendent of the heat treating department of the American Spiral Spring & Mfg. Co., Pittsburgh.

James R. Buchanan has been added to the field metallurgical staff of the Detroit district sales office of Union Drawn Steel Co.

A. R. Ellis has been elected president of Pittsburgh Testing Laboratory, following the resignation of **B. H. Witherspoon,** who remains a member of the Board.

William F. Henning has been appointed domestic sales manager of the American Screw Co., in Providence, R. I. **Walter Bromley** was made assistant domestic sales manager, and **Vincent Roddy** assistant to the general manager. **Harry Mayoh** will continue as sales promotion manager.

John H. Frye has been appointed metallurgical engineer for Columbia Steel and Shafting Co. at Pittsburgh, also serving in the same capacity for The Edgar T. Ward's Sons Co., warehousing subsidiary for Columbia.

Maurice C. Fetzer has resigned from American Steel & Wire Co. to assume the duties of assistant professor of metallurgy and metallography at State College of Washington, Pullman, Wash.

Howard Barkell has taken a position with the Phelps-Dodge Co., department of development and research at Laurel Hill, L. I.

Clarence A. Siebert has been made assistant professor of metallurgical engineering at University of Michigan.

Stephen Feduska is associated with United Engineering & Foundry Co. as metallurgist.

Norman H. Davies has been transferred from the Cincinnati to the Chicago office of North American Mfg. Co., combustion engineers.

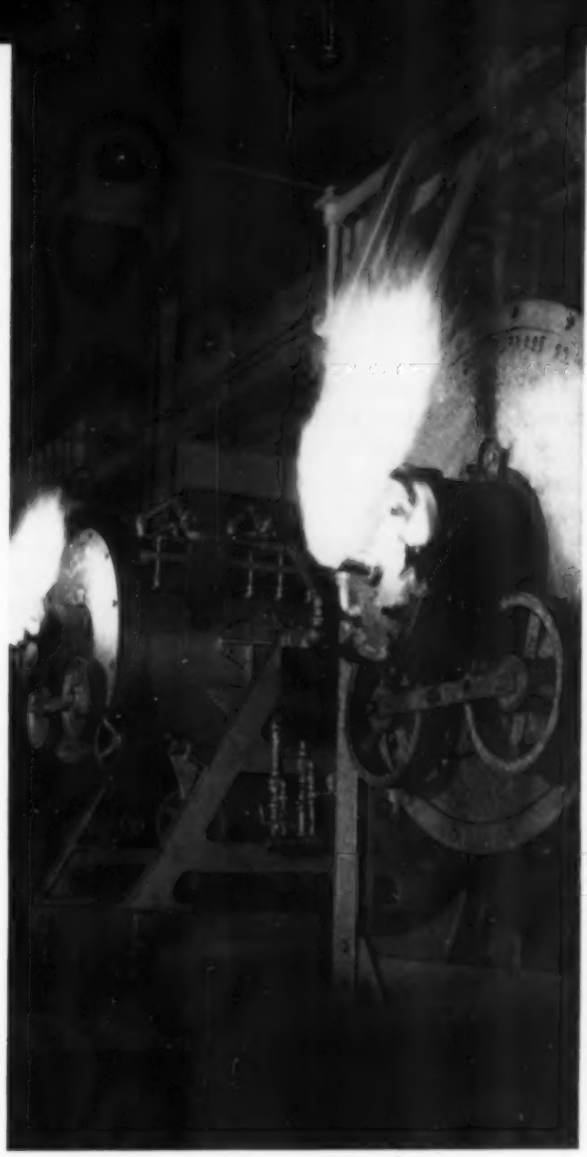
Controlled Furnace Atmospheres

By E. O. Mattocks

Industrial Engineer

American Gas Association Testing Laboratories

Cleveland



Rotating Muffle in Gas-Fired, Tilting, Furnace Shell Holds Steel Parts in Carburizing Atmosphere. Photographed at the Cleveland Tractor Co.

CONTROL of furnace atmospheres during the various heat treatment operations is becoming an increasingly important problem to metallurgists. This fact is clearly evidenced by the large number of articles and papers which have appeared on this subject in both METAL PROGRESS and *Transactions*. While this mass of material may appear a little bewildering and sometimes confusing, considerable assistance may be gleaned from it. Together with our present knowledge, it will very materially assist in determining the correct furnace atmosphere.

To control the possible reactions that may occur on the surface during the periods of preheating, holding at temperature and cooling requires a special atmosphere surrounding the metal. These atmospheres are used, generally, for one or more of the following reasons: First, to eliminate scaling completely or reduce it to a minimum; second, to eliminate decarburization or reduce it to a minimum; third, to produce a desired surface finish such as a bright surface or a blue surface; fourth, to carburize the metal; fifth, to harden the surface by nitriding, and sixth, to prepare the metal surface for a special operation such as copper brazing. To accomplish any one of these requires, generally, a special furnace atmosphere which depends upon the type of metal being heated, the temperature to which it is heated, the rate of flow of the gases over the metal, and the time at which the metal is at temperature. It may readily be seen, therefore, that no one furnace atmosphere can be employed for different metals or for different operations. Each operation and alloy composition requires a special atmosphere of its own. As a consequence, gen-

eralities on any one phase of this subject may cause more confusion than assistance, unless care is exercised by the reader in analyzing all the factors in the case up for consideration.

A great deal of pioneer work on special atmospheres has been done by trial and error methods by men who have had little accurate knowledge of what really was occurring in the furnace. That their work was a success (for which these pioneers should be given a lot of credit) is seen from the high quality of the final product. To apply one of these successful atmospheres to another job, however, unless it is exactly similar in almost all details, results generally in disappointment, not to say complete failure. Considerable fundamental study has recently been completed and some worthwhile fundamental data obtained, even though the findings are by no means complete. In other words, the exact composition of a furnace atmosphere necessary for a given metal and operation cannot even yet be predicted nor can the production of this atmosphere, if it could be predicted, always be assured. The available data, however, reduce to a minimum the amount of trial and error work required.

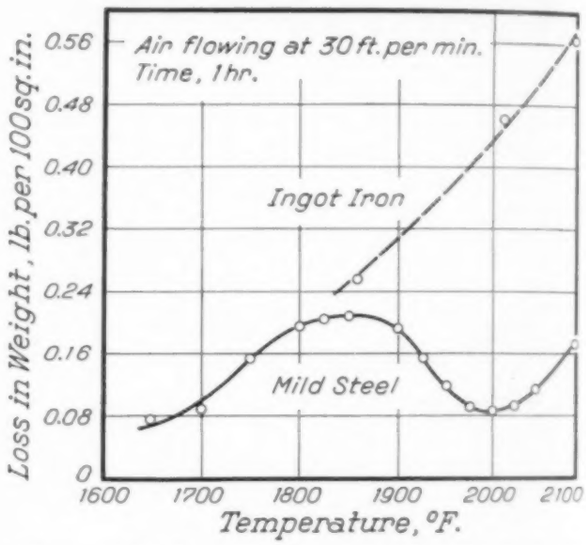
Before reviewing some of the specific applications of atmospheric control, consideration will be given to the fundamental reactions which may occur during the heating of metals. Only gaseous atmospheres will be considered; this eliminates the heating of metals in liquid baths of molten metal, salts or oil. Since only the control of the furnace *atmosphere* is to be considered, the problem of heating and quenching the metal and its effect upon the properties of the metal will not enter into this discussion.

Scale and Soft Skin

Scaling of metals is the result of oxidation of some metallic element or elements in a metal alloy by a gas or gases present in the furnace atmosphere. Generally, if the various oxidizing agents or elements in a furnace atmosphere are known and can be eliminated, scaling of metals during heating should be controlled.

It is known that pure oxygen (O_2) is a very rapid scaling medium. Air, being composed of about 21% oxygen, oxidizes metals but generally to a lesser degree. Next to air, water vapor (H_2O) is the most rapid oxidizing agent, especially with ferrous metals. In some cases this latter gas (H_2O) may be more rapid than air, particularly if the air is dry. Carbon dioxide (CO_2) is another oxidizing gas which is a very active scaler. (Some of the mechanics and rates of oxidation of these gases, especially O_2 and air, were reported by C. A. Siebert and Clair Upthegrove in March 1935 *Transactions.)* Therefore the oxidizing agents O_2, H_2O, and CO_2 must be completely controlled if scaling is to be eliminated or reduced to a minimum.

While it is very desirable in many operations to eliminate or minimize the scaling of metals, another reaction may be going on *simultaneously* which may be quite as objectionable. This is decarburization, which is the removal



Divergent Results on Scaling of S.A.E. 1020 Steel and Ingot Iron as Determined by Siebert and Upthegrove and by Heindlhofer and Larsen Respectively, Due to Differences in Composition, Porosity and Adherence of the Scale

of carbon from the surface as well as from the metal itself. Under some conditions, decarburization is the sole action to be guarded against, for the removal of carbon may produce an undesirable "skin" condition. As in the case of scaling, the gases that cause decarburization are known. Moist hydrogen (H_2) is a very active decarburizing agent. W. E. Jominy states (March 1936 *Transactions*) that moist hydrogen is the fastest decarburizing agent known to him. When dry, however, it is relatively inactive, although probably not totally inert. Likewise, oxygen (O_2) is a decarburizing as well as scaling gas. Nitrogen (N_2) as normally encountered in air and air mixtures, while generally considered inert, may actually be decarburizing in nature, especially if it is moist. While not totally contradicting Jominy, Professor Upthe-

grove in March 1936 *Transactions* has found one or two instances where moist nitrogen caused greater decarburization than moist hydrogen.

As previously stated, both scaling and decarburization may occur at the same time and at different rates. It is known, for example, that a bright, soft surface and a scaled, hard surface may exist on a single piece of metal heated in an uncontrolled furnace atmosphere. It is therefore generally necessary to control *both* of these actions, instead of one or the other, to obtain the desired surface condition on the finished product. While it is not always practical to eliminate completely all of the above gases which cause oxidation and decarburization of metals, it is possible to balance these constituents with deoxidizing and carburizing ones so that their effect is minimized.

Thus it is possible under certain conditions to restore to metals some or all of the carbon removed previously by decarburizing gases. This is frequently very desirable, as will be discussed later. Likewise, it is sometimes required to increase the carbon content in the surface of metals to some point *above* that which existed originally. Both of these conditions can be accomplished with suitable control of the gases surrounding the work during this heating operation. While hydrocarbon gases such as methane, ethane, butane, propane, ethylene and benzene are generally considered good carburizers, methane (CH_4) and carbon monoxide (CO) are probably the most active agents. Fortunately they may also be secured cheaply.

Production of Common Atmospheres

From the foregoing brief discussion of most of the basic gases encountered in a furnace atmosphere and their action, it can be readily seen that the problem of selecting a suitable furnace atmosphere is a rather complicated one. To employ an atmosphere which consists of a pure gas is, as a rule, both difficult and expensive. (There is the exception where a gas, such as nitrogen, can be obtained as a cheap by-product.) Therefore, the practical application would be a composite atmosphere made in as economical a manner as possible. Another factor to be considered is furnace construction. If a costly gas is employed, it will be necessary to have a tightly constructed furnace to minimize the loss by leakage which may cost more than utilizing a leaky furnace and making large quantities of a cheap atmospheric gas.

Various methods for securing special furnace atmospheres may be accomplished by utilizing *(a)* flue products of a fuel fired furnace directly, no muffle being employed; *(b)* flue products of a fuel fired furnace after the products have been scrubbed and some of the less desirable gases partially removed; *(c)* products of partial combustion from a separate firebox, which have been treated to remove or reduce to a minimum some of the objectionable gases; *(d)* products of dissociation of solid, liquid, or gaseous materials; *(e)* city gases, either raw or diluted with flue products or air; *(f)* gases obtained in cylinders which have been made by other processes. Which method is the best for a heat treatment under consideration can be determined only by a study of the requirements and available facilities.

The use of separate units to produce a desired furnace atmosphere is increasing steadily as greater demands are being placed on atmospheric performance. Some of these auxiliary units are intricate chemical plants employing well known principles for removing various undesirable gases; many employ dehydrating units. The gases to be removed depend on the raw gas being burned and the final requirements. Some of the gases removed by these units are sulphur compounds, carbon dioxide, oxygen, and moisture. The moisture content of the final gas can be reduced appreciably by simply cooling in properly designed coils, either chilled with cold water or even refrigerated. If practically all moisture is to be removed, various dehydrating absorbents are available such as activated alumina. Care must be exercised to insure the proper operation of all these various scrubbing and drying agents at all times, and provision must be made for renewing the various compounds as they become spent without interfering with the successful operation of the atmospheric unit. This is especially true if an atmosphere is being prepared for a continuously operated furnace.

Before continuing this discussion of furnace atmospheres, the various terms as applied to this subject will be defined in an attempt to eliminate, as far as possible, the ambiguity that now exists. The use of the terms "oxidizing," "neutral," and "reducing," in referring to the *action* of a furnace atmosphere on a piece of metal is very common. The exact meaning of these terms, however, can only apply *to* the particular atmosphere, *for* the specific metal, and *under* the exact conditions of heating en-

countered. In other words, these terms would vary for different metals and for different heating conditions. These three terms were originally used by combustion experts rather than metallurgists, and to indicate the results of combustion. For this purpose they served admirably, but it is doubtful if they can now be employed for metallurgical concepts, such as to indicate whether an atmosphere will scale, decarburize, carburize, recarburize and deoxidize.

For the purpose of this article, therefore, the original concept will be maintained. The adjectives "oxidizing," "neutral," and "reducing" will refer only to an atmosphere secured as a result of combustion. By definition, an oxidizing atmosphere is the result of the burning of some fuel and contains carbon dioxide, water vapor, nitrogen, and oxygen; a neutral atmosphere (if such a thing exists) contains carbon dioxide, water vapor and nitrogen — that is, neither an excess of air or of unburned gas; a reducing atmosphere contains carbon dioxide, water vapor, nitrogen, carbon monoxide, hydrogen, and possibly some hydrocarbons, such as methane and ethane — all the result of incomplete combustion. When referring to the action of an atmosphere on a metal being heated, the specific designation will be employed, such as "scaling," "decarburizing," "carburizing," "recarburizing," "deoxidizing," and "balanced or equilibrium atmosphere." The last two terms refer to an atmosphere that is inactive at a given temperature, insofar as the metal being heat treated is concerned.

Controlled Flue Gas

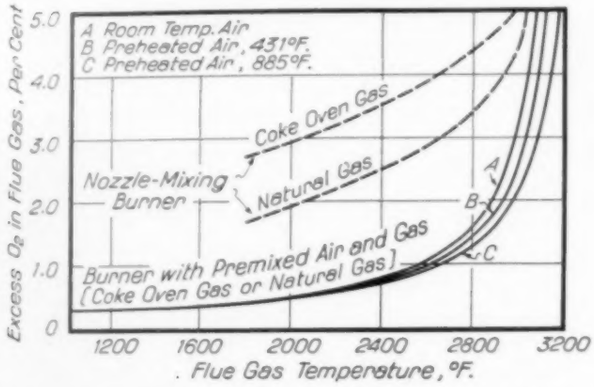
If it is desirable to minimize (but not completely eliminate) scaling on low carbon steel during a low temperature anneal, it is possible to use the flue products of a gas fired furnace directly, if a little decarburization is permitted. Since oxygen is a very active oxidizing agent, this gas should be eliminated as far as possible from the flue gases. This may be achieved by adjusting the air-gas ratio of the mixture being burned by the furnace so as to obtain a reducing atmosphere (that is, incomplete combustion, as defined above). The quantity of carbon monoxide, hydrogen and possibly some hydrocarbon gases necessary to eliminate *all* the oxygen in the flue products is not yet definitely known. (The Committee on Industrial Gas Research of the American Gas Association has initiated a study of this problem at the Association's Laboratories in Cleveland.) From some work already done and reported by the present reviewer in the October 1935 issue of METAL PROGRESS, it was found that carbon dioxide and water vapor will actually dissociate at the high temperature of a gas flame and produce atomic or nascent oxygen. The resulting reactions are shown by the following equations:

$$CO_2 \rightleftarrows CO + O$$
$$H_2O \rightleftarrows H_2 + O$$

While these reactions theoretically are reversible as shown, their direction is toward the right at the temperatures encountered within most gas flames where enough air is premixed with the gas before combustion to react with all the carbon and hydrogen present to form

Loading a Small Electric Furnace of the Batch Type. Non-oxidizing or carburizing atmosphere is maintained by dripping suitable liquid hydrocarbon through cover (shown at left under workman's elbow) on hot fan blades, where it dissociates and is rapidly circulated throughout the charge

CO_2 and H_2O respectively. As the flue gases leave the flame and are cooled, the action reverses and goes toward the left, but because of the short time which these gases are in the furnace, and because of their small concentrations, the reversal of the above actions is only partially completed within a furnace. Therefore, it is possible to have both nascent oxygen and CO and H_2 in a so-called neutral atmosphere ("neutral" again used as a combustion engineer would use it). If a small amount of excess oxygen is added to the pre-mixing device,



Amount of Excess Oxygen Needed in a Flue Gas in Order That There May Be no Dissociation of Products of Combustion With the Formation of Atomic Oxygen, Far More Active in Its Attack on Hot Metal Than Molecular Oxygen

its amount depending upon the flue gas temperature as shown by *A*, *B* and *C* in the accompanying curve, the above dissociation actions are inhibited and no CO, H_2 or *nascent* oxygen is formed, even though there is some molecular oxygen (O_2) going through uncombined.

Whether atomic oxygen is a greater oxidizing agent than this residual oxygen is questionable. One thing is certain, however; in this slightly "oxidizing" combustion no carbon monoxide and hydrogen will be present in the flue gases, while in products of a "reducing" combustion these carburizing (CO) and decarburizing (H_2) gases will be present in amounts depending upon adjustment of the mixture to the burners. From practical installations there seems to be some disagreement as to which of these atmospheres would be the better one to employ. Unless the quantity of reducing gases is great, in which case the furnace becomes uneconomical to operate as a direct fired unit, the advantage of CO and H_2 in eliminating scaling appears to be small.

Avoiding Soft Skin

The above method of reducing the scaling effect has been considered as taking place continuously during the heating of the metal. While this method is probably the most direct and exacting, as far as atmosphere control is concerned, the problem of scaling was ingeniously solved by Bengt Kjerrman of Sweden (METAL PROGRESS, December 1935). To eliminate soft spots in large bearing races which were hardened in old style, direct fired, gas furnaces, the mixture to the burners was first adjusted to produce a reducing atmosphere. Although the scaling was at a minimum, this atmosphere actually decarburized the surface on the races. As this soft surface was ruinous, the furnace atmosphere was made highly oxidizing for about the last 10 min. This scaled the surface, and by controlling the time of this "blowing" action, the decarburized skin was completely oxidized; the thin layer of oxide, being brittle, easily fell off during quenching. This principle was later applied to continuous over-fired gas furnaces with the same degree of success as with old style under-fired batch furnaces.

This example may appear to be a little out of line with our present trends, yet if this slight loss by scale can be compensated for in the original design, this method secures a non-decarburized and scale-free surface. According to D. H. Rowland and Clair Upthegrove in March 1936 *Transactions*, the width of the ferrite band or skin resulting from decarburization in moist H_2 is a function of time and temperature. If the metal under treatment requires close control, the decarburizing atmosphere can be secured by employing a muffle and a special hydrogen atmosphere. A more practical atmosphere of nitrogen and hydrogen can be obtained by dissociating ammonia. A short time before the metal is quenched, the atmosphere could be changed to air or the metal transferred to another furnace with a scaling atmosphere and the ferrite band oxidized. This oxide film will, usually, scale off during the quench.

Utilization of tight muffles or sealed hoods in a furnace permits the use of a great variety of atmospheres. It must be remembered, however, that metallic muffles may react with the hot gases and modify their effect on the metal being heated. This fact was brought out by R. J. Cowan in discussing C. R. Austin's paper in the March 1935 *Transactions*. To reduce the cost of a muffle and simplify the con-

trol of furnace atmospheres, W. M. Hepburn and H. C. Weller, in the August 1935 issue of METAL PROGRESS, explained the use of gas-hot-tubes. This principle has found very extensive use in annealing covers for sheet steel. W. C. Owen, in March 1935 METAL PROGRESS, reported an interesting and successful application of this principle to the heat treatment of spring leaves.

Another special muffle furnace for the hardening of 1040 steel shafts was described in detail by S. K. Oliver in the October 1935 issue of METAL PROGRESS. The atmosphere consisted of one part of natural gas to one of air, not precombusted but mixed cold. To reduce carbon deposits to a minimum, this mixture is introduced at the cold inlet end of the tube-like muffle with the cold shafts and passes slowly through the furnace. By allowing the cold air-gas mixture to come up to the quenching temperature gradually in this manner, the ethane probably dissociates slowly and thus combines easily with the oxygen in the air to form carbon monoxide, carbon dioxide, and water vapor. As the temperature of the mixture is increased, some of the methane will undoubtedly dissociate to carbon and hydrogen and the resulting gases combine with practically all of the remaining oxygen. As the temperature is increased the carbon monoxide and hydrogen content will also increase and the CO_2 and H_2O decrease. This action is a very fortunate condition for the free oxygen, which appears at the low temperatures where it is not too objectionable, and disappears at the higher temperatures where it would be very harmful. The presence of small amounts of CO and H_2 in the soaking zone reduces the carburizing effect of the large quantity of methane which remains undissociated and unburned. The mixing of one part of air with one of gas appears to produce sufficient free oxygen to combine with all the free carbon produced by the complex reactions, and the result is a very satisfactory atmosphere. As specific analyses were not given in Mr. Oliver's article, the exact compositions cannot be given for the furnace atmosphere throughout its length, but the net result is this: In addition to producing a scale-free shaft, a small amount of recarburization compensates for the decarburized skin existing on the cold drawn rod, from which the shafts are machined.

The demand placed on various heat treatment processes has resulted in a large number of furnace atmospheres containing more or less free hydrogen, the result of introducing pure hydrogen in the atmosphere, by dissociating ammonia, by dissociating hydrocarbon liquids, or by partial combustion of hydrocarbon gases. If an atmosphere is obtained by burning city gases or coke oven gases, and carbon monoxide appears in the final gases, hydrogen will also be there, for practically all such gases originally contain either hydrogen or some hydrocarbon. While it is customary, as a rule, to analyze only for CO and not for H_2, the latter gas should not be overlooked, for the effect of this hydrogen on the metal may, in addition to acting as a decarburizing agent, also form "flakes" in sizable pieces of metal. The role of hydrogen in producing flakes was definitely proved by I. Musatti and A. Reggiori in the July 1936 issue of METAL PROGRESS. If a metal is heated in a hydrogen atmosphere, the metal will absorb some of it, and while the rate of absorption is slow, some massive parts such as forgings and die blocks may be seriously affected when they are soaked at heat treatment temperatures to insure uniform heating. If the piece is then quenched rapidly, especially below 600° F., flakes or small internal cracks may appear. Although very little trouble has been encountered in this country from this cause, it should not be overlooked, especially if the product is to be held at temperature long and then quenched. This action appears to be more severe in the case of alloy steels than with plain carbon steels.

Bright Annealing

One of the greatest incentives for utilizing controlled furnace atmospheres has been the possibility of securing a bright surface after an annealing operation. These potentialities have been open for both ferrous and non-ferrous metals. Willard Roth in METAL PROGRESS, issue for January 1936, defined bright annealing, especially as related to high carbon steels, as "annealing without oxidation and without decarburization." During the operation it may even be possible to replace some of the carbon lost at the surface during heating for rolling.

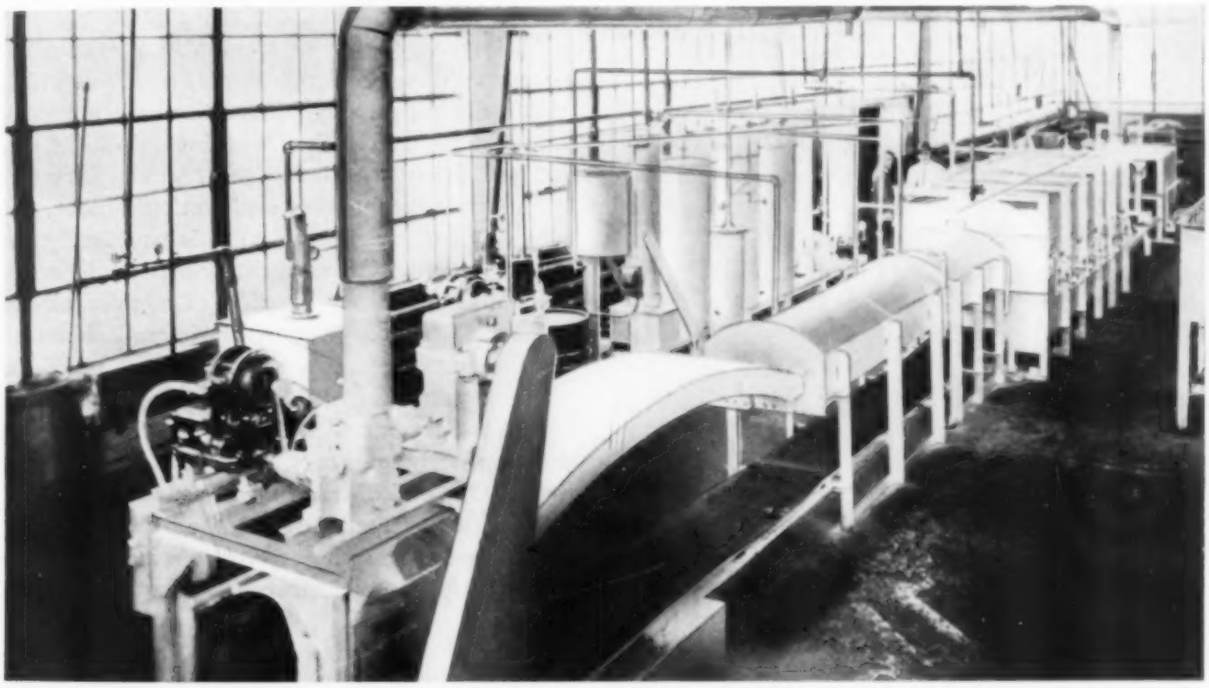
To comply with these exacting demands requires very close control of the furnace atmosphere. In practically all the work recorded in the publications, presence of free oxygen in the furnace atmosphere has been found to be very detrimental. This would be expected by remembering the fundamental reactions discussed in the early part of this article. There-

fore, regardless of the atmosphere employed in bright annealing, great care must be exercised to exclude free oxygen. The work chamber should be operated under a slight pressure to keep air from leaking in.

(*Safety Note* — A great many furnace atmospheres that are used for controlling the surface reactions of metals during heat treatment contain quantities of toxic gases, such as carbon monoxide and ammonia. Therefore, every precaution possible should be taken to insure the removal of these furnace gases from around the furnace so they will not contaminate the air in the room. This requires, generally, ventilating hoods at both loading and unloading end of the furnace, if not over the whole furnace. Extreme care should also be exercised in selecting a furnace atmosphere to insure that it is not an explosive mixture, either in the gas preparation unit or during its stay in the furnace. Leaky furnaces may be dangerous as an explosion hazard as well as a health hazard. Too much ventilation is preferable to risking a possible explosion with its ruinous results.)

The type of atmosphere to be employed for bright annealing (as is true of most atmospheres) is a function of the metal being heated. With steels, the higher the carbon content the more difficult it is to obtain an atmosphere to achieve the desired results. A good review of the requirements was given by C. R. Austin in *Transactions* for March 1935. For low carbon steels bright annealing may be done with coke oven gas, natural gas, or dissociated ammonia, but the atmosphere should be slightly carburizing. Mr. Austin doubts the practicability of annealing stainless steels and brasses without surface coloration or etching. W. Roth had very good results with razor steel and drill rod stock, employing dissociated ammonia after it was dried. Later research work revealed the suitability of dried and purified gases from partially burned hydrocarbon fuel gases. This tended to carburize the surface slightly, replacing the carbon lost in previous mill operations.

Bright annealing of copper has been accomplished in furnace atmospheres of nitrogen, steam, natural gas, and butane. The first two require initially bright surfaces for successful operation. Bright annealing of brasses, on the other hand, presents a very difficult problem because the zinc will volatilize. In working with sheet brass, the greater the amount of cold work the lower the necessary annealing temperature and a corresponding simplification of the bright annealing problem.



R. J. Cowan in Metal Progress, January 1934, Recommends an Atmosphere of Methanol and Flue Gas for the Bright Annealing of Brass. Furnace shown has open ends, gas in heating zone and cooling prolong being trapped by arched entrance and exit passages. Gas preparation plant shown against wall

Carburizing for Case Hardening

Carburization of steel parts is as old a problem as the manufacture of blister steel. Solid carburizers were and still are used extensively, although *gas* was always the carrier for transferring the carbon to the surface of the steel. The advent of controlled furnace atmospheres has opened up a new field of approach to carburization and, when correctly done, has eliminated packing boxes, carburizing compounds, non-uniformity of case, and the uneconomical condition of having only a small percentage of heating load productive.

Continuous carburizing of screws is being successfully done, J. A. Comstock reports in last April's issue of METAL PROGRESS, with undried city gas containing about 60% methane. H. W. McQuaid in July 1934 METAL PROGRESS discussed gas carburizing from a very practical angle. He stated that in order for the carbon to be dissolved by the austenite on the surface of the steel, the carbon must be in nascent or atomic form and not soot or coke. As higher hydrocarbon gases such as ethane, butane, and propane dissociate very fast, liberating varying amounts of soot which interfere with the ability of the austenite on the surface to take up carbon, the rate of deposition of carbon from a given hydrocarbon gas on work in a gas carburizing furnace can be controlled by the addition of a diluting gas, such as nitrogen, city gas, or carbon monoxide. He states further that the velocity of the carburizing gases over the steel must be above a certain minimum in order to secure uniformity. A rule-of-thumb for establishing a desirable carburizing atmosphere is: "Maintain the heating value of the gas at approximately 800 B.t.u. per cu.ft.

As previously stated in the first part of this article, carbon monoxide and methane are probably the most active carburizing agents, the latter being the faster and more reliable. The following equations show the method of securing nascent or atomic carbon from these gases:

$$CH_4 \rightleftarrows C + 2H_2$$

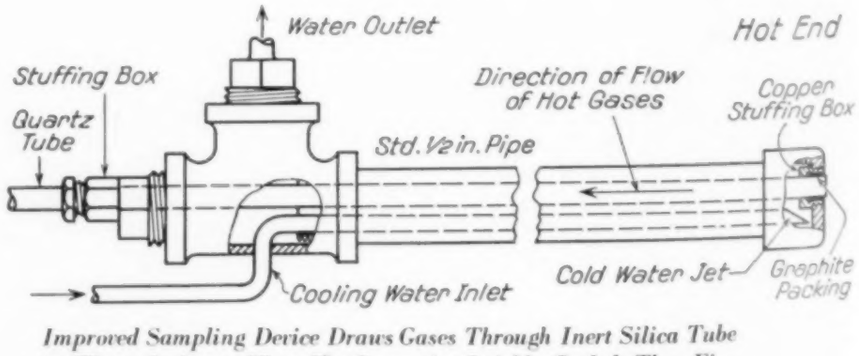
$$2CO \rightleftarrows C + CO_2$$

If higher hydrocarbon gases are employed, they are easily dissociated at carburizing temperatures into carbon, hydrogen, and methane. Since this last gas is very stable, it is practically always a product of dissociation of higher hydrocarbons. If the carbon liberated can be consumed by a diluent gas and thus controlled, the resulting methane is free to react upon a clean steel surface, giving up carbon for solution in the hot iron rather than producing soot.

Gas Analysis and Sampling

During this brief review of various types of furnace atmospheres for different heat treating processes, no gas analyses of furnace atmospheres have been given. Although some of the previously mentioned authors have reported such analyses, most of their results do not indicate, I am sure, the exact condition within the furnace. Since the fundamental reactions which occur during partial combustion are not completely known (for they will depend on the gas, air-gas ratio, flame temperature, catalytic effect of combustion chamber and work chamber, and a number of other factors) it is practically impossible to predict accurately what will result from the partial combustion of a given air-gas mixture. Therefore, an analysis has to be taken of the hot furnace gases to determine if the desired condition exists.

Most gas samples are taken with sampling tubes of copper, brass, nickel, quartz, or even iron. One end of this tube is usually allowed to attain the temperature of the furnace before drawing the sample, or else it reaches the furnace temperature before the sampling is completed. As a result of this procedure, the sample does not generally represent the furnace atmosphere from which it was taken; rather it is a gas which has been cooled slowly, allowing a readjustment of its equilibrium to take place both with respect to *(Continued on page 46)*



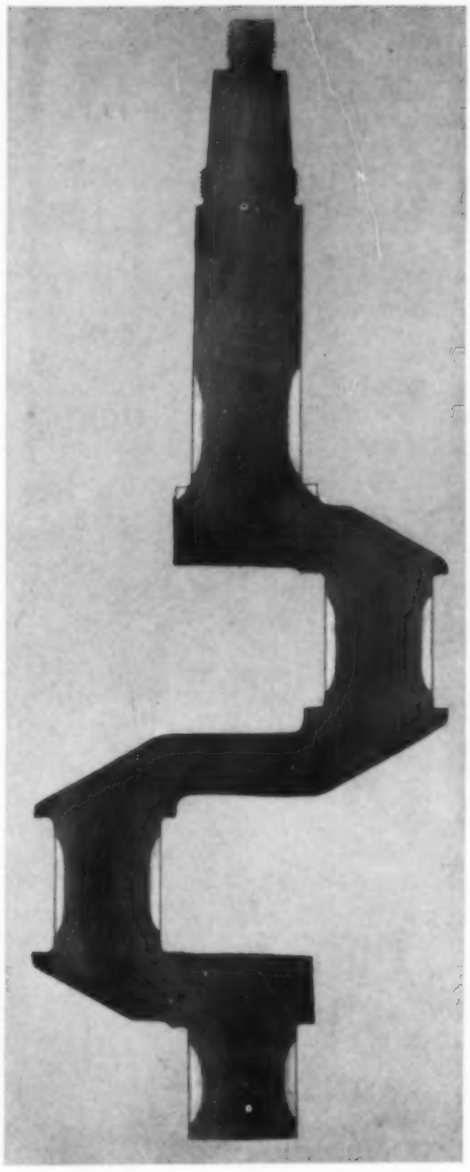
Improved Sampling Device Draws Gases Through Inert Silica Tube in Water Jacket so That Hot Gases Are Quickly Cooled, Thus Fixing or Freezing Components as They Existed in the Furnace

CARBURIZING

SINGLE QUENCH

or

DOUBLE QUENCH



The Art of Surface Hardening by Local Heat (Without Case Carburization) Is an Attractive Development, Especially for Crankshafts, Hardened on Bearings Only. Note how soft fillets can be retained, thus avoiding fatigue cracks. Courtesy Ohio Crankshaft Co.

SECOND only in interest to heat treatment in controlled atmospheres (as described in the preceding article by Mr. Mattocks) comes the matter of surface hardening — that is to say, carburizing, nitriding and cyaniding, the steels therefor, and the properties of surface-hardened parts. No less than 40 pages are devoted to these subjects in the 1936 Metals Handbook, and several important papers have recently appeared in METAL PROGRESS.

Use of gas rather than a solid as a carburizing medium is indeed a recent *commercial* development in America, although patents on some phases of the process were taken out so long ago they have expired, and Federico Giolitti in his book "Cementation of Iron and Steel" says that illuminating gas was used industrially for a carburizer in England by MacIntosh in 1825. However, this matter is briefly discussed in Mr. Mattocks' article just ahead. Those who wish more details will do well to consult the article by H. W. McQuaid in METAL PROGRESS, July 1934, and the lengthy section in the new handbook.

As a matter of fact, the great majority of carburized parts are still packed in solid compound for heat treatment. John F. Wyzalek prepared a paper for his home Chapter on this subject, later printed in METAL PROGRESS, February 1935, full of information for the practicing heat treater. He subdivided the numerous available materials on the market into three general classes: (1) Hardwood charcoal plus petroleum coke, (2) pellet and (3) hydrocarbon bone black, and presented a table appraising these classes by several characteristics such as rate of penetration and shrinkage. His experience is that solid carburizers "energized" with barium carbonate are the most desirable, due to the fact that the character of

Characteristics of Typical Carburizers

Characteristic	Hardwood Charcoal + Petroleum Coke	Pellet	Hydro-carbonated Bone Black
Rate of penetration	High	High	Low
Carbon concentration	0.90 to 1.25%	0.90 to 1.25%	0.70 to 1.00%
Lasting qualities	Good	Good	Very good
Specific gravity	Low	Mean	High
Shrinkage	Fair	Good	Very good
Thermal conductivity	Very good	Good	Fair
Freedom from undesirable impurities	Good	Good	Good

case produced is more uniform, both from the standpoint of carbon content and depth of penetration. He continues:

"Experience has also convinced me of the necessity of using carburizers in certain definite proportions of new and old material; this effects economy, greater uniformity, and less shrinkage. The general practice for charcoal-coke carburizers is to use between three and four parts of old to one part of new material. In other forms of carburizer, such as pellet or bone black types, the additions of new are appreciably less, generally being made only to compensate for the losses incurred in handling and use."

Satisfactory results — given correct packing in a good box — will ensue if the over-all variation in temperature in the furnace is no more than 25° F. Temperatures depend principally on the requirements of the finished part:

"Broadly speaking, for depth of case ranging from 1/32 to 1/8 in., temperatures between 1650 and 1750° F. are generally used. On the other hand, for depths below 1/32 in. temperatures between 1375 and 1450° F. are more suitable. Experience has indicated that the higher the temperature, the more rapid the penetration and the higher the carbon concentration at the surface of the carburized case. However, the top temperature of carburizing is limited by excessive grain growth in the steel and by the lasting qualities of the carburizer. Very frequently, especially when carburizing at temperatures around 1700° F., the last part of the run is at an appreciably lower temperature so as to diffuse the carbon in the case. Such diffusion of the carbon gives better wear resistance of the parts and minimizes checking in grinding of the hardened parts.

"Sometimes small, spindly or flat parts (such as sewing machine details) are carburized with relatively shallow cases, approximately 1/64 to 1/32 in. It is then impossible to use any other but temperatures in the neighborhood of 1400° F., since higher temperature would distort the parts and at the same time make it impossible to produce a case within close limits so as to insure a hard surface with a ductile core."

Mr. Wyzalek's article was closely followed by one by H. W. McQuaid in METAL PROGRESS, March 1935, wherein another important phase of the matter was discussed — namely, the adjustment of the details of the carburizing process to bring out the best properties of the steel. Such a problem becomes most acute when large production of low or medium alloy steel parts is involved, even though the high alloy steels (such as 5% nickel and Krupp analyses) may require complicated preliminary treatments, first to normalize them and bring them within the machining ability of available tools, and later to harden and temper them for the intended service.

Assuming, therefore, that one of the lower alloy steels, such as nickel-molybdenum S.A.E. 4615, or the plain carbon carburizing grades, has been machined into such a thing as a gear, and carburized either in gas or solid compound, one must decide whether it should be single or double quenched. In the shop the advice of textbooks is seldom followed; the economic ideal is striven for — namely, quench directly from the carburizing box and use as quenched.

Best Structure for Gear Teeth

Whether this practice is possible depends, in Mr. McQuaid's opinion, primarily on whether it will produce the desired microstructure in the case and secondarily on the over-all properties of the carburized piece. As was demonstrated by O. W. McMullan in *Transactions*, June 1935, the best life of casehardened ring gears and pinions (either in dynamometer tests or in actual service) "has been correlated with the microstructure of the case, its depth and the characteristics of the transition zone. Any heat treatment — no matter how simple — which will give such a structure will be satisfactory."

In gears, especially, what is needed is not the supposed "hard case and tough, ductile core" as much as a case with maximum resistance to wear and scoring and a maximum resistance to the development of localized stresses and warping. Long before the advent of fine-grained, shallow hardening type of gears,

chrome-vanadium gears were quenched directly from the box with quite satisfactory results. Now, with the fine-grained steels, single treatment is common, and for the same reason — namely that the high temperature quench produces a case primarily martensitic but with some retained austenite. This has proven to be more stable in service, although it may appear slightly softer in an indentation test than a gear quenched from a slightly lower temperature.

The investigations described by Mr. McMullan indicated that the maximum case strength is obtained with steels of the fine-grained type, carburized to give a case which is approximately eutectoid in carbon content. The weakest condition of the case was found in the coarse-grained steels, carburized to give a high carbon (saturated) case. These are potent considerations, second only to the need for stability for many applications where the part in service develops a high skin temperature from the energy lost through friction, or where resistance to abrasion is needed.

In Mr. McQuaid's opinion, "the best combination of minimum distortion and maximum surface hardness in such parts as passenger car transmission gears will be obtained with the minimum case and a high quenching temperature. The carbon content of a case must be as high as possible to obtain the maximum file hardness, but the amount of austenite which is retained in the thinner cases will be decidedly less than in the heavier cases. We have therefore combined a high carbon, file hard, martensitic case containing only a small amount of austenite — a structure which will be at least 85 scleroscope hard."

Double Quench

It should be remembered that the above recommendations on single quenching postulate a number of conditions not existing in many heat treatment plants, namely mass production of parts whose service life is well known, and precise metallurgical control of all steps from the receipt of raw material to the assembly of the finished machine. Thousands of parts are continually being made of plain carbon and higher alloy steels, double treated.

An interesting story about the discovery of this treatment is told by W. P. Woodside, Founder Member ⚙, in METAL PROGRESS last December. It came about by the demand for

Liquid Baths for Surface Hardening (Cyanide, Cyanamide, or Ammoniated Salts) Are Excellent for a Thin, Hard Case on Light Parts. Photo courtesy Lindberg Steel Treating Co.

gears, file hard yet tough enough so the teeth would bend together when sledged on their edge. Such a demand, unheard of in 1907, came from James G. Heaslet, a pioneer automobile manufacturer, who intended to have transmissions in his new car that were transmissions. Nickel steel (3½%) was the material, but all intelligent combinations of hardening and tempering heats failed to give the required hardness and toughness, until in disgust everyone quit, accidentally leaving one gear in the hardening furnace. Meanwhile the heat had been raised to about 1550° F. for a tool hardening job, and the gear was thrown in the oil, "for it wasn't any good anyway; it surely was overheated." Strangely enough, when a tooth was broken out of it, just in idle curiosity, a very fine fracture resulted! It occurred to Woodside that the steel plant had mixed the order and sent some toolsteel instead of nickel steel, and to check this assumption he reheated what was left of this gear to 1425° F. to see whether a thin flange left on it would harden.

"To my surprise the flange did not harden the least bit, so I decided to break out another tooth and much to my surprise and great delight the tooth did not break! I tried all the teeth very severely with the file and found them all file-hard. Slowly it dawned upon me that we had stumbled on the right method to treat these gears! It was all very puzzling, for we had tried these low quenching temperatures before in our efforts to try everything. I wondered if the preliminary high heat had something to do with the different results, so I ran another gear at 1550° F., quenched it, broke out a couple of teeth and found the fracture was very fine. I reheated this gear to 1400° F. and to my great delight I found it file-hard and exceedingly tough."

This time-honored treatment (cool in box and double quench in oil) is characterized in the "Recommended Practice for the Carburizing and Heat Treating of Gears" in the 1936 Metals Handbook in these words: "For maximum refinement of case and core; this treatment is seldom used and would ordinarily not be recommended for automotive work." So rapidly marches metallurgy!

On the other hand, direct quenching from the box without subsequent heat treatment is (in the words of the Recommended Practice) "to be used only with steels having a fine grain rating by the McQuaid-Ehn test (6 to 8 grain size); not recommended for clash gears or where long sections are involved due to distortion."

Regenerative Quench

Whatever the situation may be for automotive gears, double treatment and refining heats are common practice in shops where the highest quality of parts are manufactured—especially when they are to resist severe impact as well as wear. B. F. Shepherd, past-president, gives a table of recommended carburizing and heat treating temperatures for 15 well-known S.A.E. steels, and states the case for the "regenerative quench" in the following words (Metals Handbook, 1936 edition, page 812):

"After carburizing for the desired time, the grain size of the case and core will have increased, due to the long soaking at high temperature. If allowed to cool in the pots the excess carbide in the case will form a network between the grains, or separate in large masses, depending upon the type of steel used. This slow cooling also tends to produce an extremely coarse-grained core. After heating and quenching from a temperature which will give the best case refinement, the carbide structure will not be changed and will form an easy path for fracture, due to its intrinsic brittleness. The structure of the core will also remain unaffected.

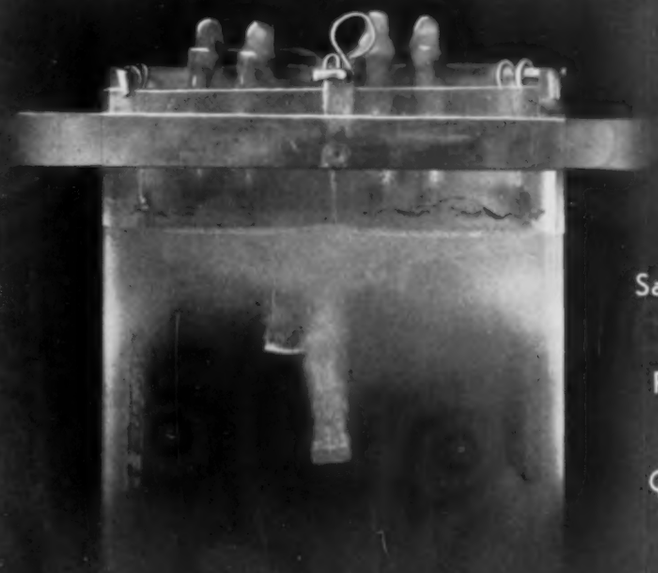
"Quenching from the carburizing temperature, where this excess carbide is in solution, will not allow it to form a network or to precipitate in large masses; the core will also be much finer grained and considerably harder, unless the carbon content is very low, but the disadvantages are (*a*) with the high carburizing temperature and long exposure case and core are both incompletely refined; (*b*) the proper quenching temperature for the core is about the same or somewhat below the usual carburizing temperature; (*c*) large work is difficult to handle on account of the heat.

"The best core condition can be obtained by allowing the work to cool in the pot, reheating, and quenching from a temperature that will refine the core and also break up any undesirable structure of cementite. This quench is called a 'regenerative quench' because it regenerates or restores the structure of the case and core. It is usually made from a definitely fixed temperature: 1525° F. for S.A.E. 2320 and 2512; 1550° F. for S.A.E. 5115, 3120, 3215, 3220 and 3415; 1575° F. for S.A.E. 3312 and 3325; 1600° F. for S.A.E. 1015, 1020 and 1025; 1625° F. for S.A.E. 6120 (all quenched in oil).

"If no excess carbide is formed, the regenerative treatment is necessary only for the refinement of the core. If the carburizing temperature is comparatively low and the time of exposure short, the grain will not grow excessively, especially with certain steels, and a quench from the carburizing temperature will produce the necessary regenerative effect."

Electro-Chemical Descaling of Metals

BULLARD - DUNN PROCESS



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Gas Atmospheres

(Cont. from page 34) itself and with respect to the sampling tube. If the sampling tube is not already excessively oxidized, small amounts of oxygen in the gas may combine with the sampling tube. In a similar manner, the sampling tube may be decarburized or carburized by the gases being taken for a sample. In addition to these reactions, the sampling tube may act as a catalyst and change the gases themselves. All these actions will be particularly accelerated at the hot end of the tube, and since the rate of removing a gas sample is usually relatively slow, the gases in the sample have an opportunity to readjust themselves in the above manner before they are cooled down to room temperature and then analyzed.

If fundamentals are to be studied or even if comparative results are to be obtained, greater care must be exercised in doing this primary task of securing a sample. In the work reported by the present writer in October 1935 METAL PROGRESS, a water-cooled quartz sampling tube was employed. The effect of cooling the tube was determined from a large number of experiments. When an air-cooled quartz tube was used no oxygen appeared in the analysis and only small amounts of carbon monoxide and hydrogen; when a water-cooled sampling tube was employed the samples of the same furnace atmosphere were found to contain considerable oxygen and greater percentages of CO and H_2.

The water-cooled tube finally developed is shown in the sketch on page 34. Cold water under pressure is discharged onto the hot end of the quartz tube. To keep the water from leaking a stuffing gland and graphite packing is used. After a year of service, mostly in atmospheres of 3000° F. or higher, this packing is still serviceable, indicating that the hot end of the quartz tube was effectively cooled, and representative analyses were obtained, for the gas sample was fixed or "frozen" — that is, cooled so fast that very little, if any, readjustment within it could take place.

It is essential to improve the ordinary sampling devices if true indications of furnace atmospheres are to be secured. If the action of a furnace atmosphere on the heated metal is to be determined, only a knowledge of the *true* condition within the furnace will be helpful.

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Automatic Handling of Mill-Length Shapes during Heat Treatment

Furnace Bell Has Been Raised (It Can Be Seen in the Upper Right Corner) and Car Bottom Is Carrying Load Forward to Where Crane With Multiple Fingers Awaits. Operator in pulpit puts selector at proper stop, closes switch, and a time-controlled series of movements follows

By E. J. Janitzky

Metallurgical Engineer

Carnegie-Illinois Steel Corp.

South Chicago, Ill.

WITH FEW EXCEPTIONS all alloy steels are heat treated for use, heat treatment being necessary to develop the high physical properties latent in them, and which warrant their use.

Progress in the manufacture of alloy steels and development in the art of heat treatment have taken place concurrently, and care is needed lest the improvement gained in their manufacture be destroyed by improper or inadequate heat treating. The chemical and physical uniformity now attained in these steels requires precise and uniform heat treatment for full utilization.

Thus the use of the most improved heat treating facilities is imperative. This applies not only to the maintenance of a uniformly proper temperature during the heating and soaking periods but also, and equally, to the maintenance of proper and uniform handling during quenching. In other words, proper time-temperature control throughout *all* of the material prior to quenching, handling from furnace to the quenching tank, and the mechanism of quenching — all these are equally important in attaining uniformity in the product. Difficulties in maintaining these essentials increase with the size and mass of the individual pieces being processed.

With this in mind, the Carnegie-Illinois Steel Corp. has installed some interesting automatic equipment at its South Works (South Chicago, Ill.) which, by its electrically controlled

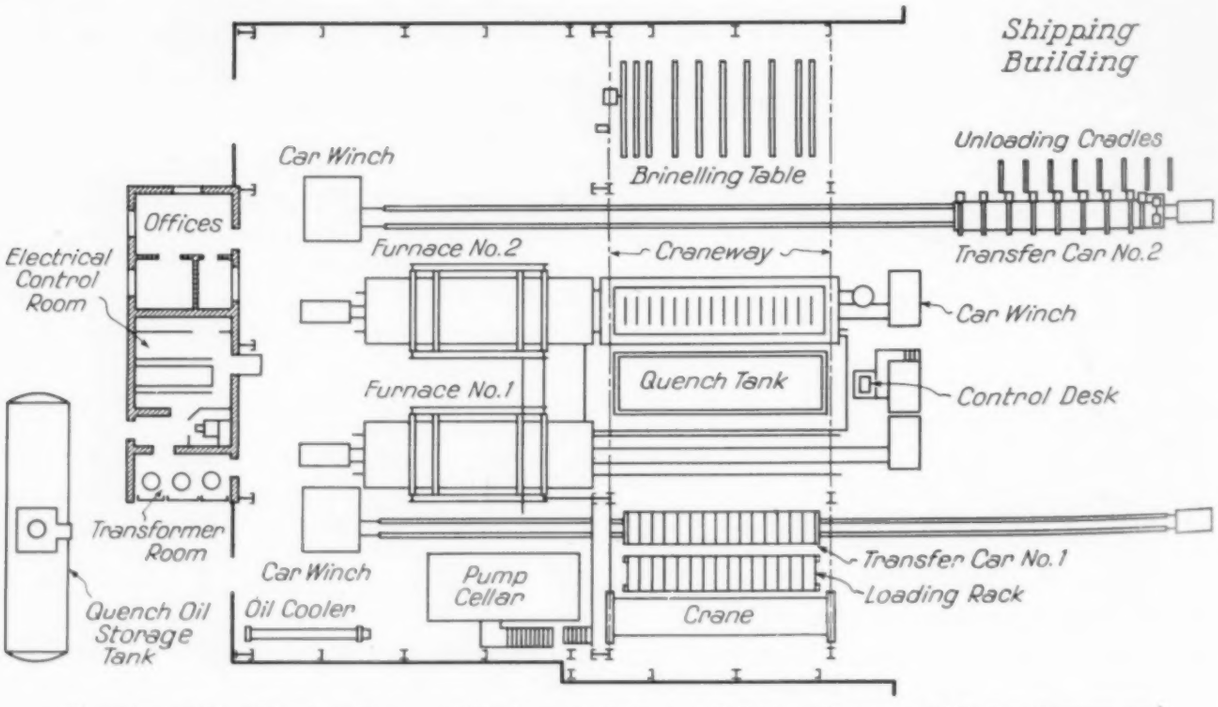
cycle of operations, eliminates those irregularities that always attend manual operation, either in handling from furnace to quenching tank or during the quenching operation. Well-developed furnace control is rather common; precise handling of hot metal *after* it is properly heated is not seen so often.

Such an installation of heat treating equipment, automatically controlled and capable of handling the mill run of bars, plates, and shapes is therefore an outstanding achievement in attaining precision and uniformity in high grade steel, both carbon and alloy. Bars up to 10 in. diameter and plates up to 52 in. wide, both with a maximum over-all length of 30 ft., may be heat treated in the new equipment at South Works. A working temperature as high as 2000° F. may be employed, thus extending the range of heat treatment to include the austenitic stainless steels in any shape, bar, structural or plate.

Two Large Car-Bottom Furnaces

The installation is housed in a building 100 by 104 ft. in area, adjacent to the alloy bar mill, and alongside the bay housing such equipment as is necessary for further processing prior to shipment, such as straighteners, turning equipment, grinders, and saws. As may be seen from the floorplan and halftones, the major equipment consists of two rectangular bell-type electric furnaces of the car bottom type. Uniform heating of the furnace load is attained by efficient design and insulation of the furnace. The load rests on a grid made of heat resisting alloy, whose top surface is 21 in. above the car bottom on which the bell rests. A double row of heating elements placed along each sidewall of this bell and a triple row of heating elements in its roof heat the load of cold metal. The heating elements on each sidewall are in a position below the level of the grid on which the load rests, so that the load is heated from below as well as from sides and top. Thorough insulation of the refractory car bottom and the bell of the furnace also assists materially in attaining an even heat throughout the load. The furnace is equipped with both sand and oil seals to prevent entrance of air and reduce scaling of the load while in the furnace.

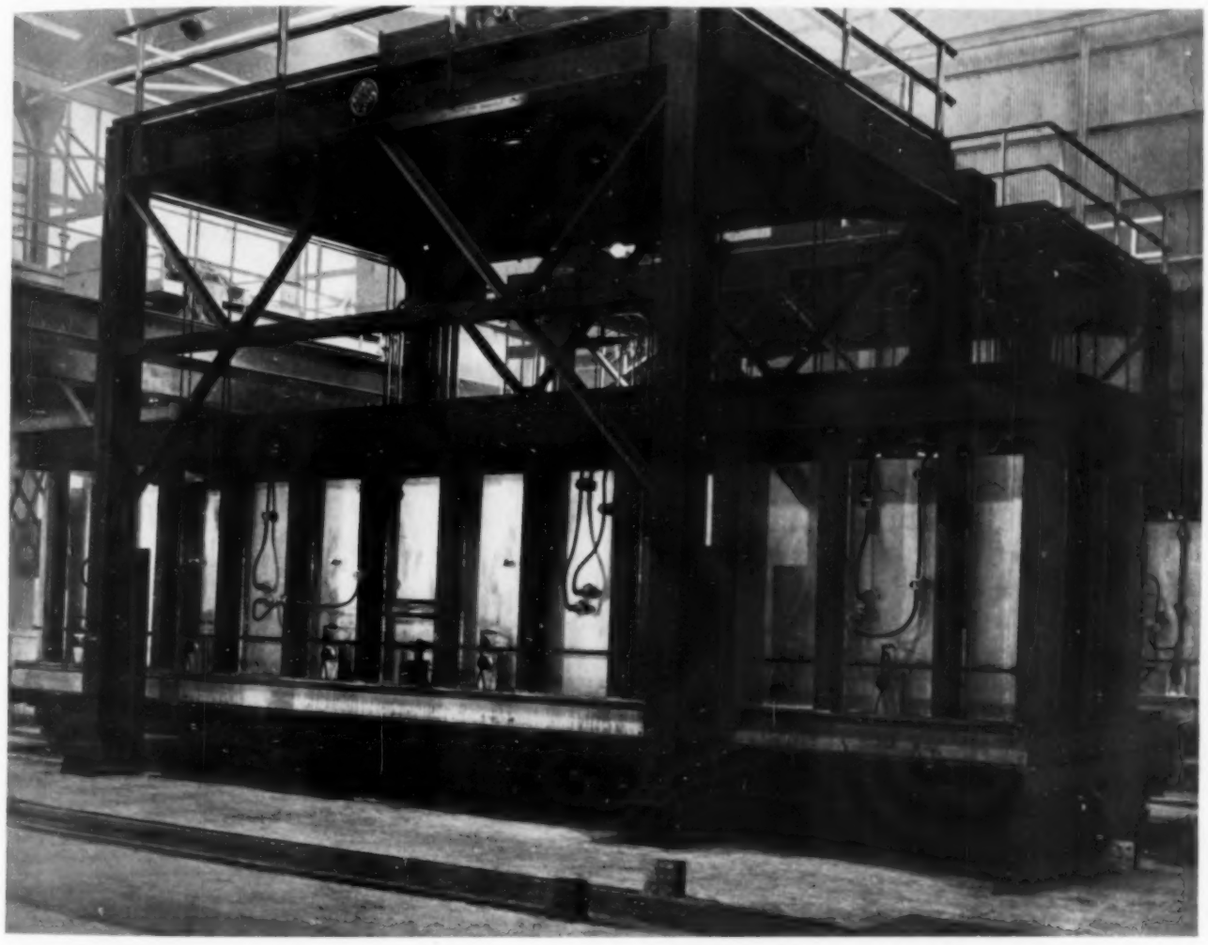
When the steel has thus been brought to the quenching temperature at the required rate and held there for a predetermined time, the furnace bell is raised and the automatic mechanism may be set to run the car bottom of the furnace forward to a position beside the quenching tank. This brings the furnace load directly under the runway of a traveling crane, fitted with a series of carrier arms spaced to fit between the load-supporting grids on the furnace



Floorplan of Heat Treating Room and Equipment, Featuring Bell-Type Furnaces With Car Bottoms and Crane Handling of Mill-Length Bars, Automatically Controlled in Definite Time-Operation Sequences

car bottom. It is therefore easy to pick up the load and lower it into the quench tank without delay. Quenching is effected by alternately raising and lowering the load, still held on the crane carrier-arms, in the quenching medium for a predetermined length of time. This affords effective and reproducible agitation of the load in the quenching medium and results in a uniform rate of loss of heat.

A unique feature, it is thought, is that all transfer operations are controlled by a single operator from the control desk. He has a full view of all manipulations, and the electrical control system is so arranged that any operation may be controlled manually, or any one of several sequences of operations will progress automatically and with a constant timing for each step. An exception is the time of agitation of the load in the quenching tank, which is controlled by an adjustable timing relay, as desired for each individual load.



The Pair of Furnaces (the One at the Rear Almost Hidden). Note the permanent structures which support the hoists for lifting the bell, and the electric busses for leading-in the heating current. Car bottom shifts to left to bring load alongside quench tank and under craneway

Either water or oil may be used as a quenching medium, the oil being pumped to a storage tank outside the building during times when water is used. Temperature of the quenching medium is maintained as desired by circulation through a refrigerating system.

The traveling crane serves not only for removing the furnace load from the furnace car and for quenching, but also may be used to load or unload the transfer cars and loading rack, to load the furnace bottoms, or to transfer a load from one furnace car to the other or to the testing table.

The present equipment is wired for no less than eleven such sequences. The operator chooses the desired sequence merely by setting a selector switch on the control panel; when he closes the master control switch this series of

operations is then carried out automatically. For example, assume that a load in the furnace is to be quenched and loaded into the second furnace for tempering. The operation of the equipment will be as follows:

1. The crane is brought to its standby position by manual control.

2. The selector switch is set for the desired cycle for quenching the load and the master control switch is closed. The following operations then take place automatically:

(2*a*) The furnace bell rises.

(2*b*) The furnace car is moved into position under the crane runway.

(2*c*) The crane moves into position over the car with the carrier arms in position beneath the charge.

(2*d*) The charge is lifted and carried to position over the quenching tank and lowered into the quenching medium.

(2*e*) The charge is alternately raised and lowered in the quenching medium for a predetermined period of time.

(2*f*) At the completion of the cycle the crane comes to rest with the load draining, over the quenching tank.

3. The selector switch is then set for the next automatic cycle for charging the load into the tempering furnace and the master control switch is again closed. This causes the following sequence:

(3*a*) The furnace bell of the second furnace, which has been set for the desired tempering temperature, rises.

(3*b*) The furnace car moves into position under the crane runway.

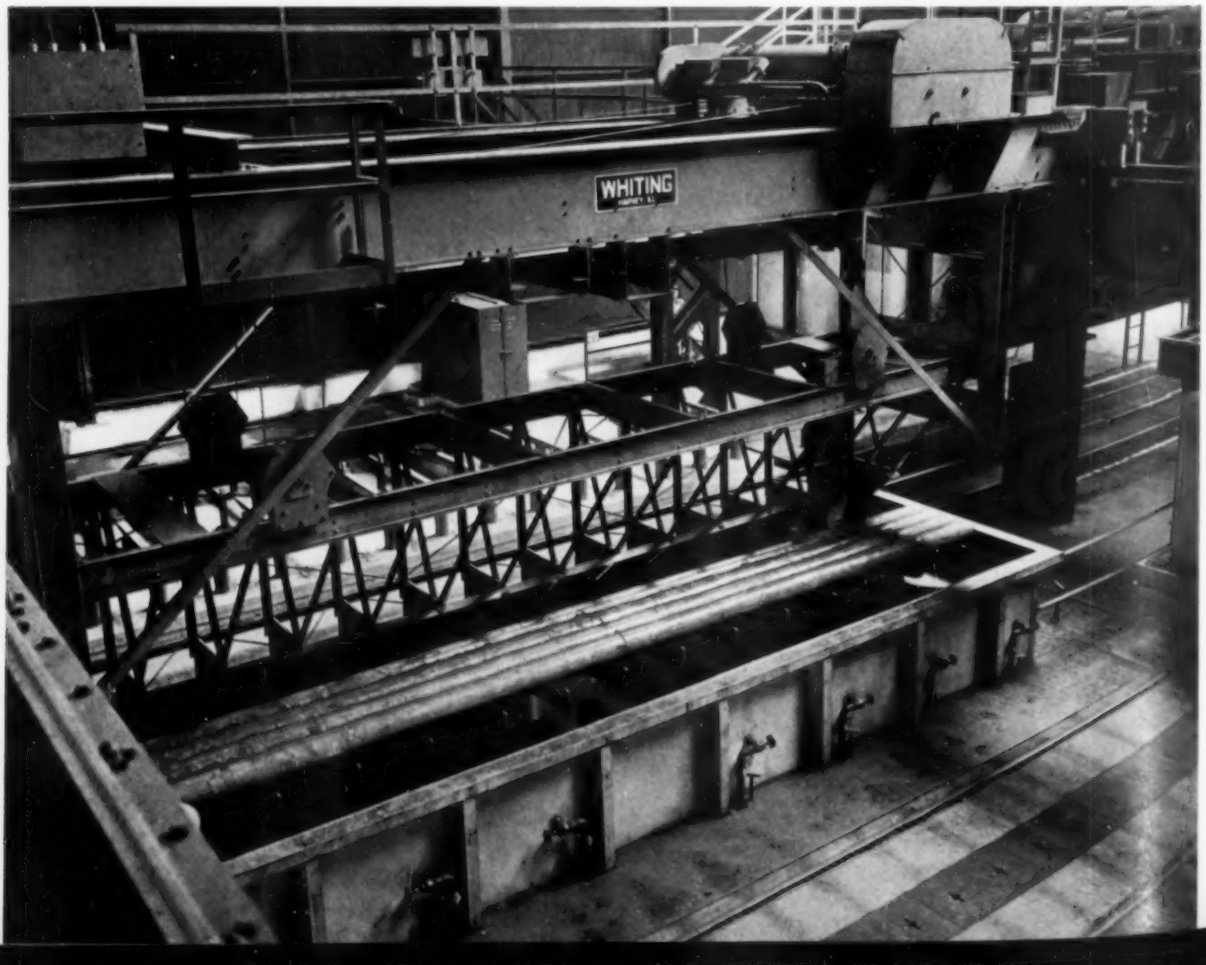
(3*c*) The crane places the charge on the furnace car and moves back to clear the car, coming to rest in its standby position.

4. The furnace car is moved into position under the bell which is then lowered. Both of these operations are by manual control.

After the heat treated material has been determined to be satisfactory in regard to physical qualities by specified tests, it is transferred to the adjoining building and given the surface finish desired by the customer. This finishing department is equipped with saws, straightening and turning equipment, and also with grinding and lapping machines adequate to give any finish desired, even a high luster finish on stainless steel so necessary for decorative structural purposes.

All heat treating and testing is under the control of a supervising metallurgist who must make certain that the material will meet the customer's requirements. The precision of this equipment, operated under technical control, assures a uniform product to meet the most exacting requirements.

Special Crane Is Holding a Load of Large Alloy Rounds Over Quenching Tank, After Cooling, Ready for Transfer to Annealing Furnace Car Bottom or to Inspection Table



REFRACTORIES

RECENT TYPES, USES & UNIT COSTS

By O. L. Day

Harbison-Walker Refractories Co.

Although Continuous Tunnel Kilns Are Producing Much Refractory Brick, the Round Bee-Hive Still Burns Much Excellent Fireclay and Silica Brick. Photo by Henry Mayer

REFRACTORIES is a term which has been applied to those materials used to withstand the effect of thermal, chemical and physical forces created in a furnace. In the development of the many different designs of furnaces, various kinds of refractories have come into common use to meet the varying conditions.

Even though the determination of the proper refractory to use for a particular purpose may not be an exact science, it is more than mere guesswork. No one brick has yet been made that will meet all conditions under which firebrick are used. When something is known about the conditions under which a furnace operates, we can consider the various properties of the different refractories and balance these with each other to select the material that should give the longest life or best service. We most commonly think of a refractory in terms of its ability to withstand temperature, but it is truly an exceptional case in which *heat* is the only agent that effects its final destruction.

For the present discussion we will endeavor to consider each type of refractory, with a brief outline of its general characteristics, the type of furnace in which it is used, and information as to its cost. The figures quoted on prices have been taken from a current trade journal.

A general grouping of the different refractories would be

1. Fireclay brick and ground fireclay.
2. High alumina clay brick.
3. Silica brick.
4. Basic brick and loose refractories.
5. High temperature cements.

Of these, the most widely used refractory is fireclay. The first sub-division of this class would be by qualities. Standard specifications cover this in terms of "high duty brick", "inter-

mediate duty brick" and "low duty brick" or as it is commonly called, first, second and third quality materials. Materials of these classes are manufactured in at least 29 states, and it is the exceptional furnace that does not require the use of fireclay brick.

The routine of manufacture may be outlined as follows: Grinding of raw clays to proper size, adding water and mixing, molding to shape, drying and firing. Most generally two or more clays are used in making the batch. The main constituent is flint clay but as this has no plasticity, even when very finely ground, it is necessary to mix with it a soft or plastic clay to form a bond.

Different processes of making may be employed. The one still referred to as "hand made" was first used, and the present method is to grind the crude clays in a wet pan, measured out in the proper proportions with the correct amount of water. This mixture is allowed to soak or "temper" for some days, and the brick is then shaped to size in a hand press. This kind of brick is still used for certain work and almost all the difficult and large special shapes are molded by hand.

Machine Made Brick

Next came what is termed "machine made" brick, also referred to as "steam pressed". In this method, after the clays are mixed they are forced through a die by pressure from a steam press or auger machine. The emerging column of green clay is cut to size and each block repressed in a mold.

In recent years more brick are being made by the power press and drypress process, wherein the clays are ground dry and then screened to size, thus permitting a more careful control over the sizing of the clay particles.

After the brick are finished in the wet or green state they are dried, preparatory to being placed in the kilns for firing. Downdraft, compartment and continuous kilns are used in various plants. A careful control must be maintained over the temperatures at which the brick are fired. Most generally the brick are separated or sorted as to degree of burn, so that a stock of one kind of brick might consist of (*a*) hard, (*b*) medium to hard, (*c*) medium and (*d*) light to medium brick.

The above gives some idea of the variables that could occur in the making of clay brick, and each of which can be taken into consideration in selecting a brick to meet the required conditions. These would sum up as follows:—

1. Kind of clay used.
2. Process of manufacture.
3. Texture of brick as effected by both grind and burn.

As previously mentioned, this class of refractory is used in practically every type of furnace but we will review some of its most general uses. The steel industry is the largest user of refractories and the blast furnace is the starting point of all iron and steel products. This furnace is lined with clay brick and can be taken as an example of how brick may be made from the same clays to meet different requirements.

Steel Plant Uses

As is well known the iron ore, coke and limestone are charged at the top of the blast furnace and hot air is blown in through the tuyeres in the lower part to cause combustion of the coke and reduction of the ore. The molten iron and slag accumulate in the bottom or hearth and as the burden of the furnace moves down, additional material is charged at the top. Bear in mind that the diameters at the hearth are from 16 to 27 ft., which enlarges to 20 to 28 ft. at the mantle and then tapers down to 11 to 19 ft. at the top in a height of 75 to 100 ft.

In the lower sections the firebrick is directly in contact with the molten iron and slag. Above this is a section in which the temperatures are high, from 3200 to 3300° F. In the main shaft the brickwork is subject to temperatures of about 2700° F. at the bottom, and to 300 or 400° F. at the top, as well as the severe abrasion of the moving charge. You can readily see that one kind of brick cannot meet all these conditions. In the lower section a brick of high refractoriness, as well as dense texture is needed, and the brick made for this part of the furnace is called "hearth quality" and "bosh quality". In the middle section, the resistance to abrasion is becoming more important and accordingly, the brick used is made to withstand abrasion as well as comparatively high temperatures. This is referred to as "inwall quality". In the top section abrasion is the whole cause of wear and a very hard dense brick known as "top quality" is used.

Connected to each blast furnace are three or four hot blast stoves. These are purely regenerative units in which combustible gas, taken

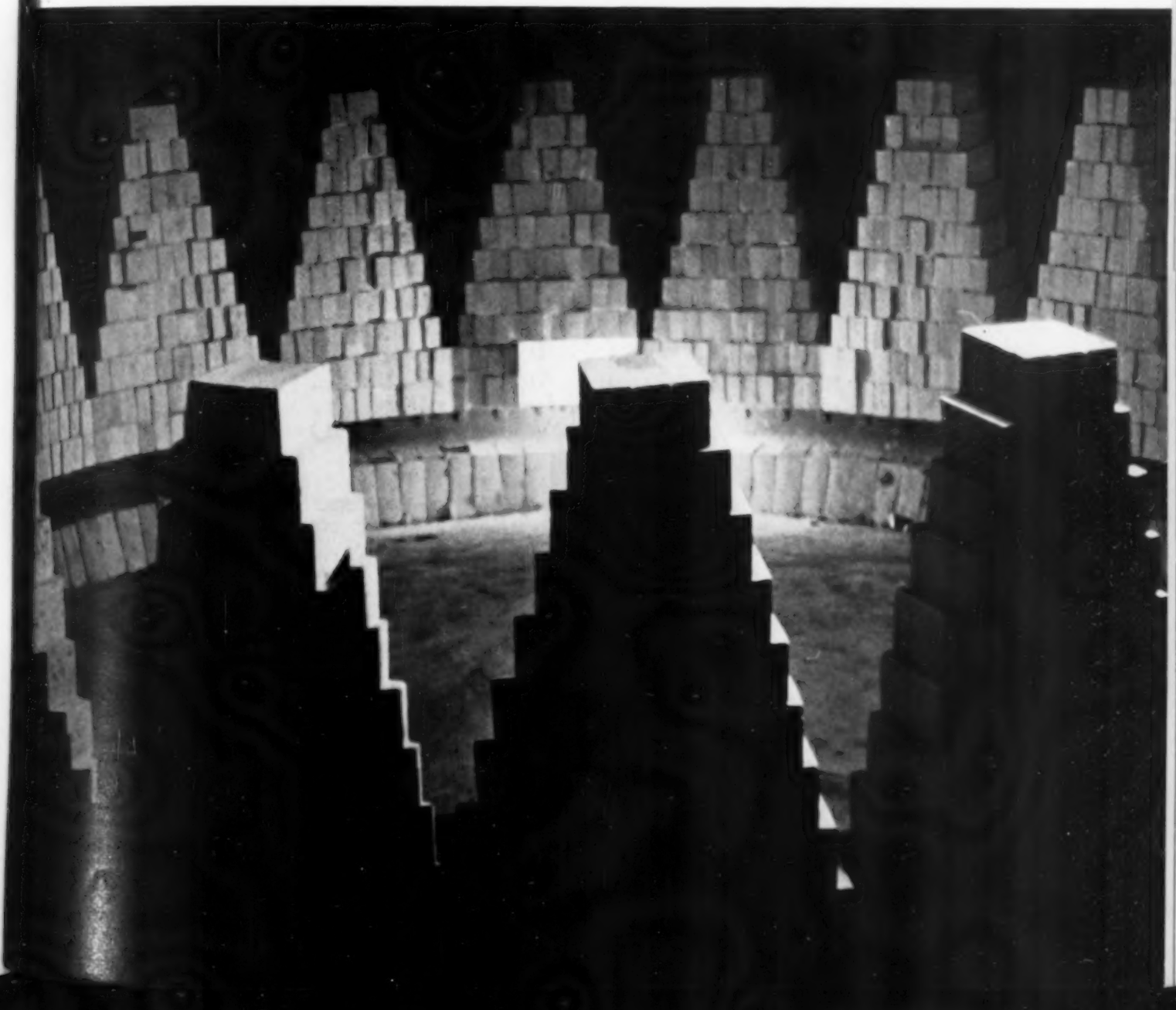
from the blast furnace top, is burned to heat a porous mass of brickwork. When these "checkers" are hot enough air is blown in a reverse direction through the stove to be heated for blowing the furnace. The brick needed for this work must be one that will absorb heat and give it off, withstand the repeated temperature fluctuations, and resist slagging from trapped flue dust.

On account of the high temperature as well as velocity of the gases, clay brick are used to line the large pipes connecting these two units. Furthermore the ladles used to carry molten metal and slag are lined with clay brick. So you see that clay brick alone have been used throughout the blast furnaces' operation.

In the refining of pig iron to steel, clay brick take an important part but other refractories are also used as will appear in the sequel. In the openhearth furnace the checkers, checker chamber, flues and stack are built of clay brick. As the steel ingot moves on to the finishing mills, we find clay brick being used in soaking pits, heating furnaces, welding furnaces and annealing ovens.

Foundries are also important customers of the refractory maker. The operation of a malleable furnace, for instance, imposes especially severe conditions on the clay brick that are used entirely for their construction. The iron is melted and refined in a confined space and the temperature and velocity of the gases are high. As soon as the furnace is tapped, a section of the roof, called the "bung", is removed and cold metal charged through it. Such brick are subjected to very severe spalling conditions as well

The Brick Mason Learns to Stack His Brick in Orderly Fashion Before Building a Furnace Top. Photo by Van Fisher at Timken Steel and Tube Co.



as high temperatures. Hand made brick have long been used for this work but in recent years pressed brick have been developed from some clays, and these are doing equally well.

Lime kilns, pottery kilns, cupolas, brass and copper furnaces, continuous ceramic and metallurgical kilns, boilers, gas generating units, glass furnaces, carbon furnaces and heat treating furnaces all require the products of the clay brick manufacturer for their operation.

Naturally, with such a wide range of materials, a corresponding variation in price occurs. At present these are from $35 to $50 per thousand, depending on quality and district in which they are made.

Continuous efforts through research are being made to improve fireclay brick along lines that may be outlined as follows:

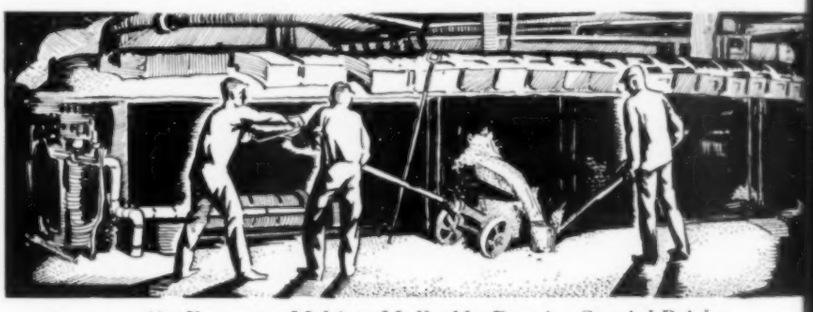
(1) Methods of producing mixes of maximum temperature stability from the clays of the various producing districts, since this material is the chief constituent of the body of the brick, (2) proper proportioning of the grain size to increase strength and decrease permeability to gases and slags, (3) removal of entrapped air during pressing, (4) the development of correct firing treatments to mitigate failure of brick from thermal shock, (5) production of malleable furnace brick of better resistance to the various types of spalling and to slag attack so pronounced in this type of metal melting, (6) more complete control of the properties of blast furnace brick to make them resistant to carbon monoxide disintegration, and (7) the development of checker brick of better thermal properties.

High Alumina Refractories

The second division mentioned at the outset is commonly known as high alumina refractories, but really these materials should be grouped with clay brick. Theoretically, pure clay when fired would contain about 45% alumina (Al_2O_3) and 54% silica (SiO_2). Any clay which analyses more than about 45% alumina contains also certain alumina ores or minerals. High alumina brick are therefore made from such clays and in general, those used for refractories are known to mineralogists as diaspore, bauxite and gibsite. (With this division we should include refractories made from kaolin clays which come chiefly from Georgia.)

High alumina brick are divided into classes in accordance with their alumina content; these are 50%, 60%, 70% and 80% respectively. Their refractoriness is above that of first quality fireclay brick and in general are more refractory as the alumina content is higher. Another property has been improved which is possibly a larger factor in their favor; namely, these brick have a higher temperature of incipient vitrification. Probably the best way to consider the advantage of this property to a furnace builder would be by an example:

Consider a furnace that operates at a temperature of 2900° F. built of clay brick in the arch having a fusion point of 3100° F. However, the beginning of incipient vitrification in the clay brick might be at 2700° F. This means that two or three inches of the inner face of the brick has begun to soften or vitrify, the amount depending on the time heat has been applied and the radiation that is taking place. When this furnace is cooled this vitrified or partly vitrified section will tend to spall or crack, and improved service in such a place might be expected from a high alumina brick.



Air Furnaces Melting Malleable Require Special Brick

The fusion point of the selected brick might be only 100° F. or so above the clay brick but incipient vitrification might not begin until a temperature of 3000° F. is reached. This is 100° above the temperature in the furnace, so the brick would retain their texture and not be affected when the furnace is shut down and gradually cooled. This does not mean that high alumina brick can *always* be used economically in place of clay brick, as comparative final cost based on service in the determining factor.

The cement industry is the largest user of these brick. Some rotary kilns use one or more of the different grades in addition to clay brick and while the 70% class is the most commonly

used, all of the other grades are being used, depending on operating conditions.

With the advent of larger furnaces and hotter gases in openhearth furnace work, high alumina brick have been used successfully for checkers. Glass furnaces are also working with these materials in different parts of their construction. They have proven economical for the linings of various types of oil fired furnaces and open arc furnaces. High pressure oil stills, boilers and heating furnaces are using them. The development of these materials has taken place in recent years and the application of this refractory will have a wider use and growth as service data are developed and the reseach work of the ceramic laboratories progresses.

This research work includes efforts to (1) eliminate the high porosity of the fired materials, an after effect resulting from the usual firing treatment, (2) induce the growth of the mineral mullite in the 70% alumina class, or stable corundum in the 80% alumina class, to insure better volume stability at elevated temperatures during usage and (3) utilization of the various bauxite deposits to produce refractories comparable with those made from the diaspore clays, since bauxite, upon firing, shrinks more than diaspore.

The price of high alumina may be considered as increasing directly as the alumina content of the brick does and it varies from $75 to $300 per thousand.

Silica Brick

While silica does not have as wide a field of use as clay brick, it is an important factor in furnace work and without it many of our large furnaces could not have been developed. Silica brick is made by crushing and grinding, in wet pans, hard silica rock, known as ganister or quartzite. The most important American deposits of this are found in Pennsylvania, Wisconsin and Alabama. During the grinding about 2% of lime is added which combines with the finest particles of silica during firing to give a bond to the brick. Silica brick thus contains about 95 to 96% silica (SiO_2).

The green brick must be handled very carefully and the time of firing is about twice as long as is required for clay brick. A clay brick is always molded larger than the finished brick is to be, as all clays shrink when fired; however, silica has a permanent expansion that occurs during firing due to a volume increase caused by the allotropic transformation that takes place in the crystalline mass. Silica brick also expand thermally when again heated; this must be considered in their use, as it is 1.5% or about 3/16 in. per ft. which is fully reached at about 1200° F. To allow for this expansion, open joints are sometimes left in the brickwork, which close as the furnace is heated; again, the buckstays of the furnace will be loosened as expansion takes place.

The physical strength of silica brick at high temperatures is much higher than that of clay brick under the same conditions; this explains their general use for arches of large furnaces. However, they will spall and crack with sudden temperature changes, particularly between the limits of 500 to 1000° F. To avoid this, the furnace in which they are used must be heated gradually and cooled in the same way.

Openhearth furnaces are built with silica brick in their main arch, sidewalls, port arches and bulkheads. In glass furnaces the main and port arches and sides use silica. As silica brick have a thermal conductivity about 25% higher than clay brick they have been utilized in by-product coke ovens and gas retorts. Electric furnaces, bessemer converters and copper smelting reverberatories are also some of the furnaces using large quantities of silica brick.

For a comparative cost I will refer only to eastern silica brick, which is $45 per thousand, f.o.b. works.

Research projects on this important class of refractories include (1) bonding mediums, either in addition to or as a substitute for lime; (2) more complete control of the inversions of the various allotropic forms of silica by more effective catalyzers; (3) greater density by variations in molding processes.

Basic Refractories

Basic refractories are magnesite, chrome and dolomite. Magnesite is a magnesium carbonate ($MgCO_3$) which when pure is composed of 47.6% magnesia (MgO) and 52.4% carbon dioxide (CO_2). The crude material is found in nature in two mineralogical forms, crystalline and amorphous. The crystalline types, such as come from the state of Washington and Central Europe, is the one generally used for refractory purposes.

The crude ore is calcined in either shaft or rotary kilns to drive off the CO_2 and at the same time the material is sintered into grains, being

NEW IDEAS IN FURNACES

IN THE PAST three or four years, METAL PROGRESS has been so fortunate as to secure permission to publish detailed drawings of several new and interesting furnaces. In some cases a history of the development of the design prefaced a statement of their performance, which made the subject even more interesting.

One of the best, as well as the earliest (November 1932), covered a 28-ft. continuous normalizer, oil fired, for automotive forgings. An interesting account by J. M. Watson, past president ASM, took the reader through the difficult transition period wherein the batch-type and its cousin the car-type furnace gave way to the continuous type. The first of the new type furnaces to be installed were subject to various "growing pains" — the conveying mechanisms were weak in a number of connections and details. Furthermore, several changes had to be made in the false arches and burner arrangements so that the stock going through would be uniformly heated. While they were a great improvement over the batch type furnaces, they still were not ideal. In Mr. Watson's words:

"All the furnaces had a conveyor hearth consisting of a series of flat-topped slabs, so designed that balls on the trailing corners fitted into sockets on the leading corners of the next; their under side also had grooves to fit the skid rails, and deep recesses to catch a finger on the pusher mechanism.

"Such a design required some rather large variations in section throughout the casting, a variation which should be avoided in parts which are successively heated and cooled. Heat checks usually start here and work their way into the casting, eventually cracking and warping it beyond use or repair. Heavy slabs of metal also cut down the efficiency of the furnace; too much heat is absorbed and carried out of the tunnel by the conveyor. Finally, a solid bottom of metal prevents circulation of hot gas through the charge, which is essential for low temperature operation."

Fortunately, the furnace was strongly bound with steel, so no trouble was had with brickwork or doors. What can be expected from a really good furnace can be inferred from Mr. Watson's state-

ment: "No major repairs to brickwork have been necessary in ten years; carborundum bricks lining the combustion chambers are removed at intervals of about two years, and at such shutdowns all brickwork is pointed up with high temperature cement."

These early troubles were put to good account in the design of new furnaces, whose general drawings are reproduced in the article. The hearth is carried on arches over eight combustion chambers, and all arches and supporting walls are perforated so as to form a checkerwork for diffusing the flow of hot gases and absorbing a store of heat. The roof slopes downward from charging door somewhat past midlength, where is located a low arched rib separating preheating zone from a high-roofed soaking zone. Combustion gases are drawn off just above entrance and exit doors, and thence through recuperators to separate chimneys.

The alloy trays carrying the work are formed like open-top rectangular boxes, with one long side missing. They butt one against the other and are pushed through the furnace, so the rear side of the leading box forms the front side of the one following. Dimensions are about 48 in. by 12 in. by 6 in. high. Uniform thickness is ½ in.; side, ends, and bottom are slotted freely for gas circulation. Low flanges on the bottom engage the rollers and keep everything on the track, and bottom and side are corrugated for stiffness. Every effort has been made to avoid changes in section.

Mr. Watson concludes his article by giving 11 fundamentals of good design, and they are worthy of being framed by every furnace user.

1. Reduce number of moving parts inside furnace to a minimum.
2. Avoid change in section on all heat resistant castings.
3. Ventilate carriers or trays freely, for gas circulation.
4. Avoid mass in carriers, which take heat out of furnace to no good purpose.
5. All parts (moving or stationary) should have ample strength and generous bearings.
6. All portions of the mechanism should be accessible for inspection and repair.
7. Interlock all devices into one automatic unit for efficient operation.
8. Control path and volume of hot gases inside furnace.
9. Maintain slight over-pressure.
10. Utilize waste gases to preheat air for combustion.
11. Insulate furnace efficiently.

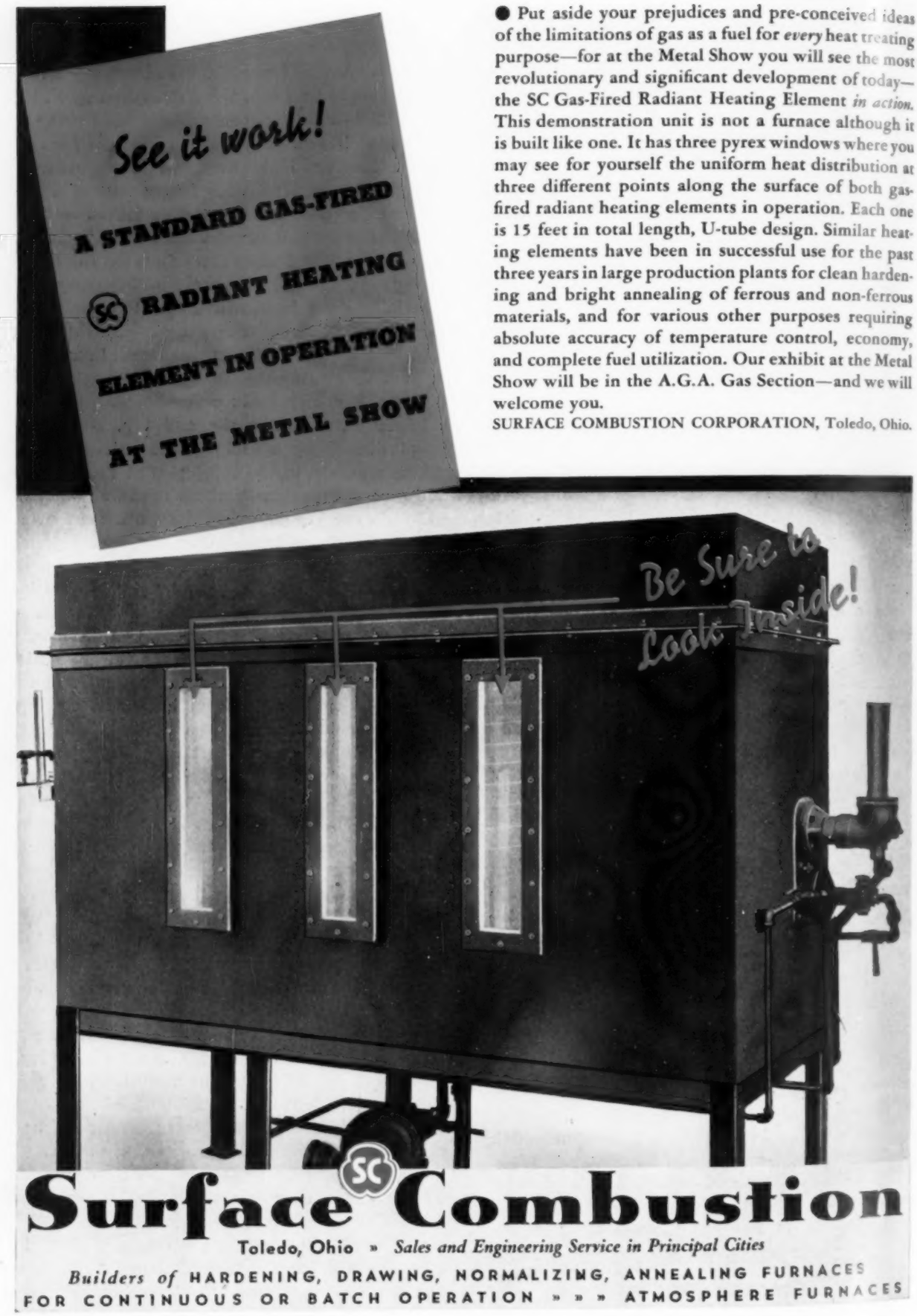
Vertical Furnaces

In the August issue of METAL PROGRESS some rather unique furnaces were described by F. E. Harris — unique because instead of having a horizontal hearth they have a vertical hearth (if the term can be so used). Full page drawings give the general design of a pair of such furnaces for heat treating spring leaves — one a high temperature furnace for hardening, and the other a low temperature furnace for tempering. As pointed out by the author, they are especially good in crowded quarters, and for special applications rather than the ordinary field well served by the more conventional designs made by furnace builders.

The low temperature furnace is in effect a tower with solid walls and top, separated longitudinally by a metal baffle extending up the axis nearly to the top, open at the bottom and placed on columns about man height. An endless conveyor carrying the work goes over a driven sprocket at the very top, and around an idling sheave at the bottom; it is loaded and unloaded at one point, with conveyor trays in the open and at convenient height. Dual combustion boxes are located centrally at the lower part of the shaft; hot gases travel upwards against the descending stock, across on top and then down the other side of the baffle, leaving the furnace comparatively cool at the bottom of the charging side of the furnace.

The mechanism of heat transmission is as follows: The insulated chamber or shaft, open at the bottom of both legs, affords a pull on the products of combustion only as the gases on the cold side in cooling are heavier. This natural flow assures the definite travel of the gases, without undue chimney effect or channeling. The hot gases issuing from the combustion boxes are directed against the central steel baffle, in a thin stream distributed across the width of the furnace. These hot gases travel along the vertical baffle, affecting immediately the thermocouple located at the top of this leg, and serve to hold the stock at temperature. These gases, descending, will maintain the correct travel for uniform heating regardless of the furnace width since the greatest volume of gases will flow through the coldest channels. This automatically compensates for non-uniform loading and radiation.

For high temperature work, say 1500° F. or above, the construction of the conveyor is a limiting feature. Since *(Continued on page 69)*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A STANDARD GAS-FIRED
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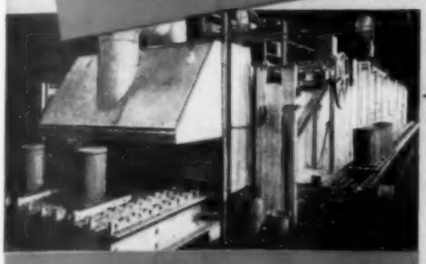
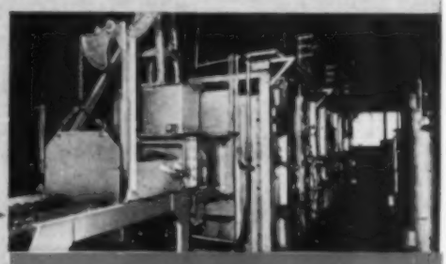
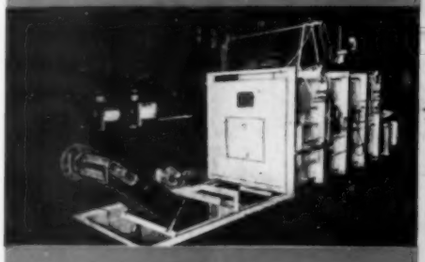


CARBURIZING

Pack or compound method

"Eutectrol" Gas Process

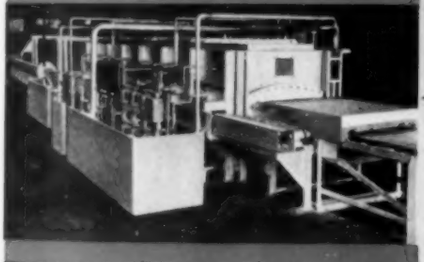




HARDENING

Direct Fired

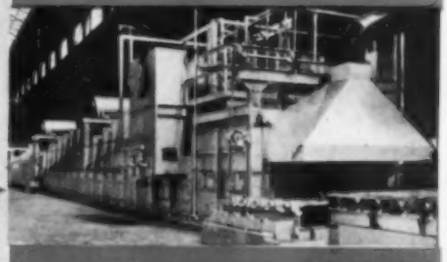
Clean Hardening
(Controlled Atmospheres)

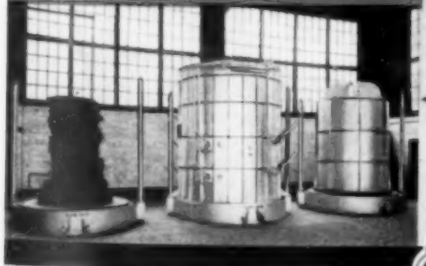


ANNEALING

Bright Annealing
(Controlled Atmospheres)

Direct heat,
cycle conntrolled





Spheroidizing

Forging

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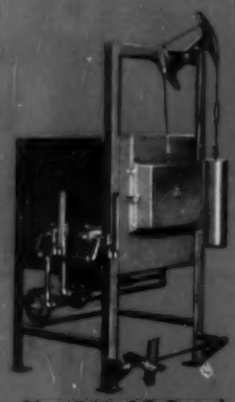

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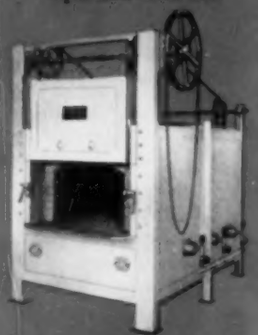

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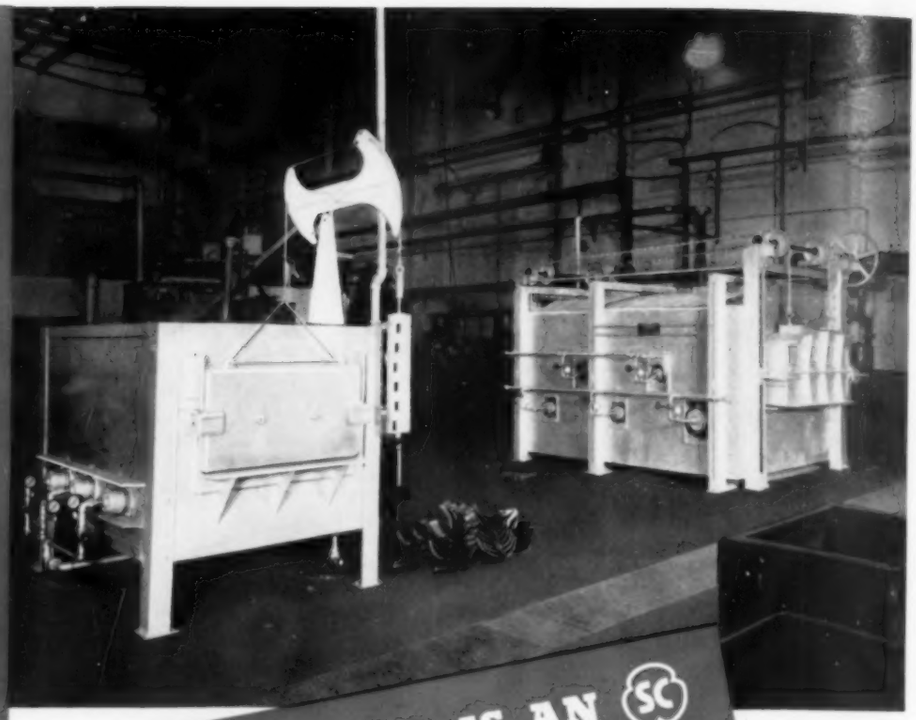

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New Furnaces

(Continued from page 65) the entire load must be suspended in a hot furnace, the application of this type of vertical furnace is in heating comparatively light, short parts for a relatively short time. However, a unit of this type has been operated successfully at Flint in the Buick plant for heating ¼-in. stock for leaf springs to a temperature of 1550° F., on a 20-min. cycle, at the rate of 2500 lb. per hr.

In the high temperature furnace, the median baffle is of refractory and the top shaft for the conveyor is water cooled and heavily insulated. Main burners are located at the top, directed across the furnace and down the leg in which the work ascends. Auxiliary burners direct some flame down the descending leg, and others are located near the unloading station. Radiation from hot gases or incandescent brickwork is now the predominating factor in heat transfer.

Mr. Harris believes that with moderate temperatures, a vertical furnace of any reasonable width or capacity should be seriously considered. "Its advantages are fairly obvious. Where vertical headroom is available, the required floor space is very small for the capacities obtained. Fuel efficiencies are high, due to the low temperature of the waste gases. Continuous operation fits in well in most production lines; furthermore, practically all of the conveyor may be employed for productive work. Stock handling is most convenient, as the operator, standing in one position, loads and unloads the exposed conveyor easily."

Radiant Tube Heaters

Furnaces for doing the same work as those described by Mr. Harris — heat treatment of spring leaves — but of more conventional shape, were described by W. C. Owen in METAL PROGRESS, March 1935. The important new idea in this is (aside from controlled atmosphere) the use of radiant tubes as heating units. But first to state the furnace's requirements:

1. Large capacity, even with long soaking heat — that is, efficient heating in a long furnace. The walking beam type of conveyor had proven itself, and it had the added advantage that it could be driven from one end, and would require no openings in the sidewalls, discharge-end wall or bottom. It also was ideal for hearth ventilation and heating from units placed below.

2. Hardening without surface decarburization — that is, atmospheric control. The furnace was too big to think of an interior muffle or tube to enclose the work, but, as an alternative, the products of flame combustion could be carried in a number of tubes, bent like hairpins, placed above and below the hearth. This also required a *tight* furnace to avoid waste of valuable (and somewhat toxic) gases.

3. The temperature must be controlled precisely, and its distribution must be uniform within 5° F. (plus or minus) through the soaking zone.

Mr. Owen describes how these requirements were reached both in the high heat and the low heat furnaces. We can here spare but a little space for the most interesting feature — namely the radiant tube heaters — especially since they are now being used so widely for heating the annealing box covers in the new sheet mills (see page 120). In Mr. Owen's words:

"These heaters are made of cast chromium-nickel-iron alloy tubing, 3 in. inside diameter, ¼-in. wall, joined at the inner end by a return bend so the unit looks like a huge hairpin. In the heating zone of the 38-ft. furnace, 28 heaters are located above the work and 16 below. Twelve are below the hearth in the soaking zone.

"At the open end of each of these U-tubes, outside the furnace, a gas burner is centered. A lazy flame extends down the axis of the tube, gradually combining with the air drawn in or aspirated around the burner through the open end of the tube. This is true diffusion combustion of streams of gas and air, moving in parallel, non-turbulent flow. (The principles have been thoroughly explained by W. M. Hepburn, in "Metal Progress" for September 1932.) Such a flame can be drawn out to great lengths, and the turbulence introduced at the U-bend is therefore of advantage in mixing the unburned gases with the remaining air, so combustion will be completed before the outlet is reached.

"At the exit end of each tube is a short chimney. Just above its connection with the radiant tube, this chimney is narrowed into a venturi throat. At its bottom is a small jet of compressed air at 1 lb. This device acts as an eductor for the burned gases, and gives the necessary gentle suction for drawing combustion air into the entrance end of the radiant tube, around the gas flame.

"Temperature distribution of U-shaped tubes has been very carefully determined in the laboratory, under various conditions of operation. In our furnaces these figures are about as follows, for a flame which produces temperatures of 1600°

F. just inside the furnace sidewall: 12 in. inside, 1640° F.; 24 in. inside, 1690° F.; 30 in. inside, 1700° F.; 36 in. inside, 1700° F.; 42 in. inside, 1690° F.; 54 in. inside, 1640° F.; 68 in. inside, 1590° F. These are indeed small."

Circulation of Hot Atmospheres

In correcting the shortcomings of the direct-fired furnace, where the products of combustion bathe the work being heated, one real advantage of that type of heating has been lost. Even though the hot gases do react chemically with the surface of the metal, they simultaneously give up their heat in a most efficient manner. It results that the most careful atmospheric control, either in muffles, electrically heated furnaces or furnaces heated with gas-fired radiators, is likely to involve stagnant gases surrounding the metal. If the operating temperature is low, too low for efficient heat transfer by radiation, the heating rate is impossibly slow; on the other hand, at higher temperatures, where radiation is efficient, uneven temperature distribution results from part of the charge being "in the shadow."

In either event, energetic gas circulation has been applied by the leading furnace builders with great success. Small batch-type furnaces may conveniently have a motor-driven fan, placed either below a perforated bottom on which the charge rests, above the charge just under the furnace cover, or in a separate fan chamber placed at the side. A general discussion of this problem of heat treatment by forced convection was printed in METAL PROGRESS, November 1935, by W. A. Darrah, and details of a very large tempering furnace operating on these principles by E. M. Kingsley in the issue for January 1933.

Forced convection applies to the transfer of heat from source to work by circulating gases, moved mechanically. The source of heat may be electric resistors lining the walls of a closed chamber and the gases may merely go 'round and 'round without coming out anywhere. Or the circulating gas may go through the furnace and bathe its contained load, then into a dutch oven where it is mixed with hot products of combustion for another round trip. It is entirely possible, however, to accomplish the same thermal results by circulating inert or reducing gases heated in a stove or recuperator; in this case, all of the thermal advantages obtainable by circulating products of combustion may be derived with the additional advantages of preventing or controlling surface changes such as oxidation, discoloration or carburization.

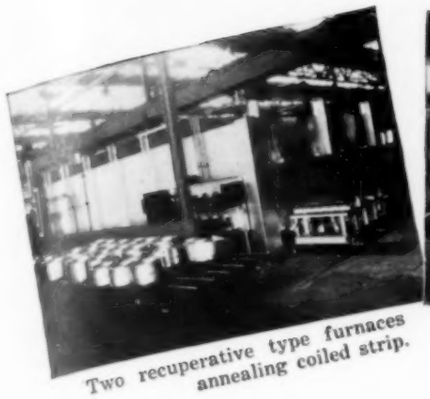
There is no theoretical limit to the temperatures at which forced convection may be applied with advantage, but from a practical standpoint Mr. Darrah finds that the mechanical equipment for moving gases is still somewhat unsatisfactory above temperatures of 1600° F. As a result, forced convection has been largely (but not exclusively) employed in the temperature range between 200 or 300° F. as a low limit and 1500 to 1600° F. at the top.

It is apparent that when circulating gases are used to take heat from an outside source into a furnace, a temperature difference between "source" and "sink" is necessary. This temperature *difference* is the important factor in determining the amount of heat transferred rather than the temperature of the work. In order to obtain reasonably close control, this temperature difference should range between 50 and 100° F. Practical considerations will usually dictate the permissible temperature drop, which in turn will determine the volume of circulating gases.

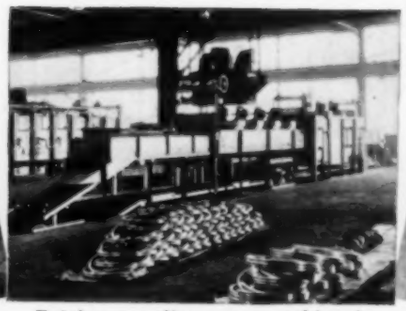
The optimum velocity of the circulating gases appears to be around 1000 ft. per min. This is subject to variation, being higher at higher gas temperatures. Higher velocities also serve to apply the heat with greater uniformity, but velocities materially greater than 1500 ft. per min. ordinarily involve excessive power and special fans without corresponding advantages.

Mr. Kingsley's article describes an automatic heat treating machine for transmission gears, which includes a unit operating on the principles laid down by Mr. Darrah. Gears are carried through the machine by overhead carriers, adapted, in fact, from an automatic electroplating unit. The drawing oven is a very long tunnel with narrow longitudinal slot in its roof through which the work-carriers slide.

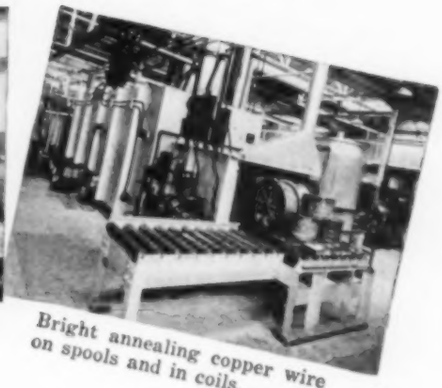
It takes about 80 min. to pass from entrance to discharge end. In order to bring the work to drawing temperature as soon as possible, the entering end is maintained at 520° F., whereas the larger part of the travel is in air at 450° F., the correct degree. All portions of this oven are adequately insulated, a false bottom is built end to end, and the hot end and the cool end each has its own circulating fan. The fans are operated so that the pressure inside the drawing chamber at the loading opening is just about equal to the atmosphere, so there is no great loss of heat by blowing off hot air or sucking in cold.



Two recuperative type furnaces annealing coiled strip.



Bright annealing copper tubing in coils and straight lengths.



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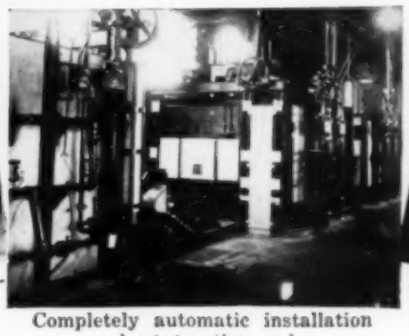
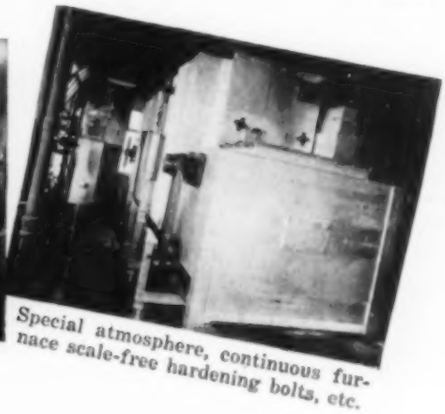


Completely automatic installation —heat treating axles.



Special atmosphere, continuous furnace scale-free hardening bolts, etc.

Refractories

(Continued from page 63)

then called "dead burned magnesite". It has lost about 50% of its former weight and the commercial material will contain about 85% magnesia (MgO) and 7% iron oxide (Fe_2O_3), the latter being necessary to give the proper bond. In this form it is used for basic open-hearth and electric furnace bottoms.

Dead burned magnesite is finely ground, mixed with water, molded and burned in brick shapes. While the fusion point of magnesite is about 3900° F. (much higher than clay or silica), and the brick are very strong when cold, they will stand but little load under high temperatures and will also crack and spall very easily when subjected to changes of temperature. They are also quite expensive, consequently magnesite brick are not used to any great extent except to withstand a basic reaction where the brick comes directly in contact with the metal, basic slag or material being heated. Their main use is in steel making furnaces, copper converters and copper refining furnaces.

However, in some types of smaller furnaces they are used with an improvement in service over clay brick. Where steel is being reheated prior to forging or shaping, and scale from the work falls on the bottom of the furnace, a basic brick will resist the fluxing action of this scale much better than fireclay.

Basic materials, including basic brick, are priced on a tonnage basis which at present is $65 per ton. Allowing for a variation in unit weights this is equivalent to $320 to $350 per thousand.

Chrome, although classed as a basic material, is almost neutral in chemical reactions. Formerly, it had a limited use to separate magnesite brick from silica brick when the construction required these materials next to each other, as in sidewalls of openhearth furnaces. As chrome brick have, for some years, been cheaper than magnesite, chrome is now being used in sidewalls of steel furnaces.

The chief deposits of chrome ore are in Africa, India, Greece and Cuba. As there is no appreciable permanent change in volume when heated, it is not necessary that the raw ore be calcined before it is used. Therefore the slopes in openhearth furnace bottoms are sometimes constructed like rough (*Continued on page 82*)

Gas Fired Conveyor Type Bright Annealing Furnace

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Bright or oxidized finish. Full automatic or manual operation.

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Forging in Hammers, Upsetters & Presses

Editorial Review

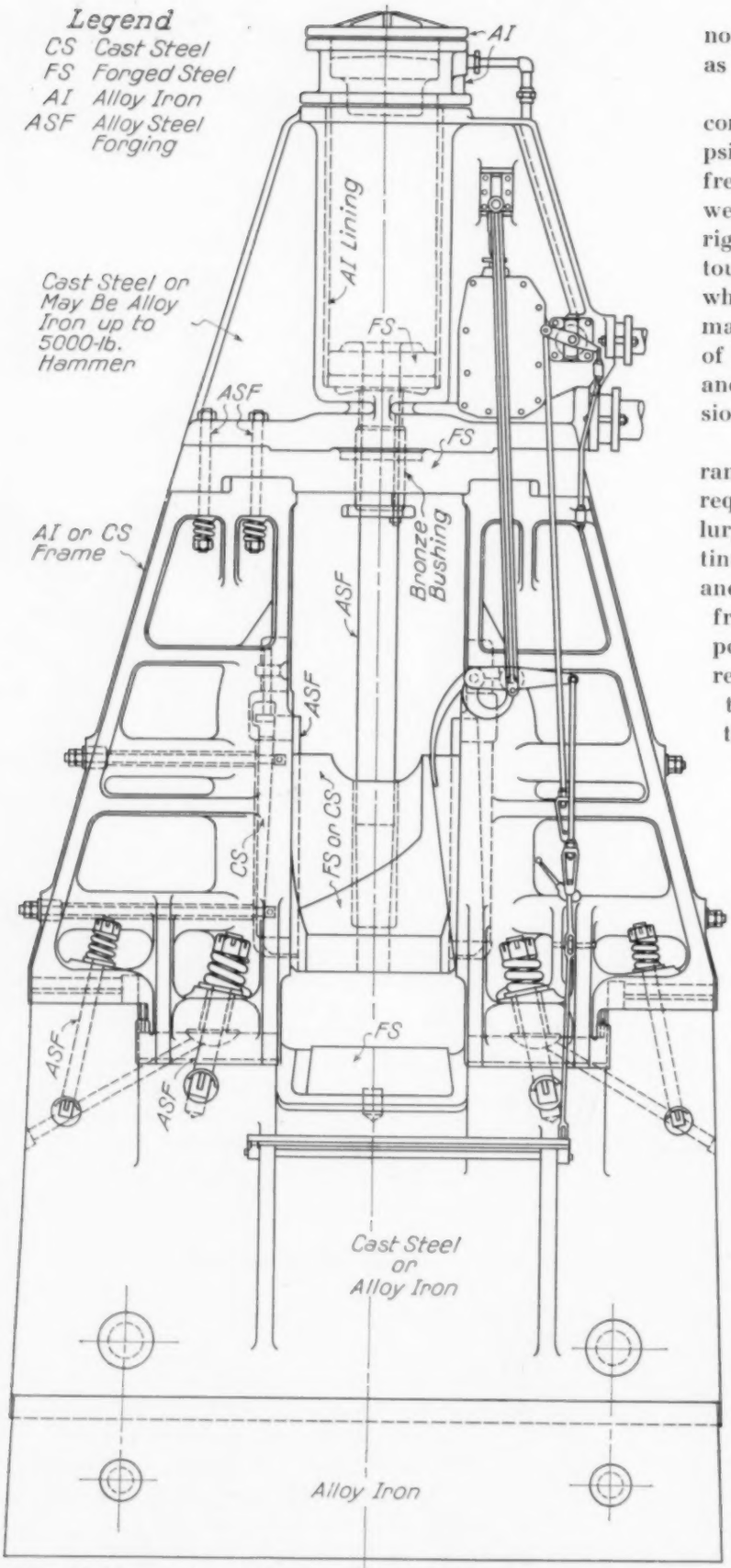
12,000-Lb. Steam Hammer Forging Alloy Steel Crankshafts at the Plant of Buick Motor Co., in Flint, Mich.

Photograph by Mort Walton

WITH the advent of the automobile and mass production, the drop hammer, steam hammer, and forging machine received first attention from designers and engineers. Revolutionary improvement in this equipment was necessary to handle the constantly mounting varieties of alloy steels and to keep pace with production requirements. Newly designed and modernized machines made possible the mass production of forgings close enough to size as to require a minimum amount of finish machining. As this goal was approached, it became obvious that still further savings would result if these modern forgings could be finished by pressure, as in a coin-finishing operation, thus bringing them still closer to the desired size and reducing subsequent machining and scrap loss. In fact the micrometer had displaced the machinist's rule as a measuring instrument. It is doubtful if the design problems applying to machine tools as a whole contain a more severe demand for metallurgical exactitude than that which is encountered in the design of forging hammers and forging presses.

Materials for Hammers

Although the thought that forging hammers are self-destructive tools has been accepted with restraint by the using industries from the start, there has been one long and constant struggle by the makers to prolong the life of the tool in the face of maximum and continuous duty. The circumstance that 85% of the impact type of forging equipment is over ten years old provides evidence that in a measure the problem has been successfully dealt with along these lines. R. E. W. Harrison has kindly sent some



Sketch of Large Steam Hammer, Showing Materials of Construction for the Principal Parts. Courtesy of Chambersburg Engineering Co.

notes about the modern forging hammer, viewed as a metallurgical problem.

"Cylinders, for instance, whether used on compressed air or steam at approximately 100 psi. pressure, must be of close-grained metal, free from defects, and possess long life against wear. The tie plate, which is added to give rigidity to the top part of the structure, must be tough, durable and wear resistant. Side frames which move appreciably at the moment of maximum impact must possess a certain amount of resilience, but above all they must be sound and free from mechanical defects and inclusions.

"Piston heads, piston rings, piston rods, rams and anvil caps can only meet present-day requirements when made to the closest metallurgical specifications and heat treatment," continues Mr. Harrison. "Anvils must be tough and wear resistant, but above all must be free from defects which could provide a starting point for cracks. Tie bolts must be tough, wear resistant and thoroughly reliable — otherwise their failure, while endangering the tool and the work, has the more serious possibility of injuring the operator or his helper.

"Having regard to the accuracy which is rightfully demanded in modern forging — an accuracy which can only be obtained by nearly perfect matching of dies — it is extremely important that the ram guides possess the maximum resistance to wear and also sufficient resiliency to enable them to withstand a terrific impact, or slap, every time a blow is struck. Upon operating and throttle valves depend accuracy of control, safety, and economy of motive power.

"Originally cast iron was the only element available for cylinder, frame and anvil elements. However, there has long been a steady growth in the use of cast steel for large hammers and (in the last five years) of a nickel-molybdenum iron for hammers up to 5000 lb. rated capacity. Very few hammers are made today of common gray cast iron, and these almost without exception are confined to sizes below 1000 lb. in falling weight, it having been realized that the economic balance shows up better when a higher quality material is used.

"The cast steel in most general use for hammer frames is usually founded at Chambersburg Engineering Co. to the fol-

lowing chemical specification: 0.25 to 0.30% carbon, 0.20 to 0.25% silicon and 0.60 to 0.80% manganese. Annealing 'in the sand' is almost universal practice. Particularly in the case of anvils and rams it is necessary that this cooling in the molds be not hurried for any reason. The usual rule is to remain in the sand for at least one day for each ton of weight. This means that some of the heaviest castings must be reduced in temperature gradually over a period of not less than 3½ to 4 weeks.

"The nickel-molybdenum iron, melted in a reverberatory air furnace, is favored by us on account of its durability and shock resistant qualities, together with its highly satisfactory vibration characteristics," writes Mr. Harrison. "Representative tests, made by the Wayne Laboratories on 1.2-in. cast bars, showed total carbon 3.00%, combined carbon 0.80%, manganese 0.70%, silicon 1.30%, nickel 0.60%, molybdenum 0.40%. As cast the 1.2-in. bars developed 4500 lb. transverse strength and 0.103 in. deflection; tensile strength was 50,000 psi., and Brinell hardness 235. After oil quenching from 1400° F. and drawing 1 hr. at 560° F., the corresponding figures were 4675, 0.109, 52,900 and 331."

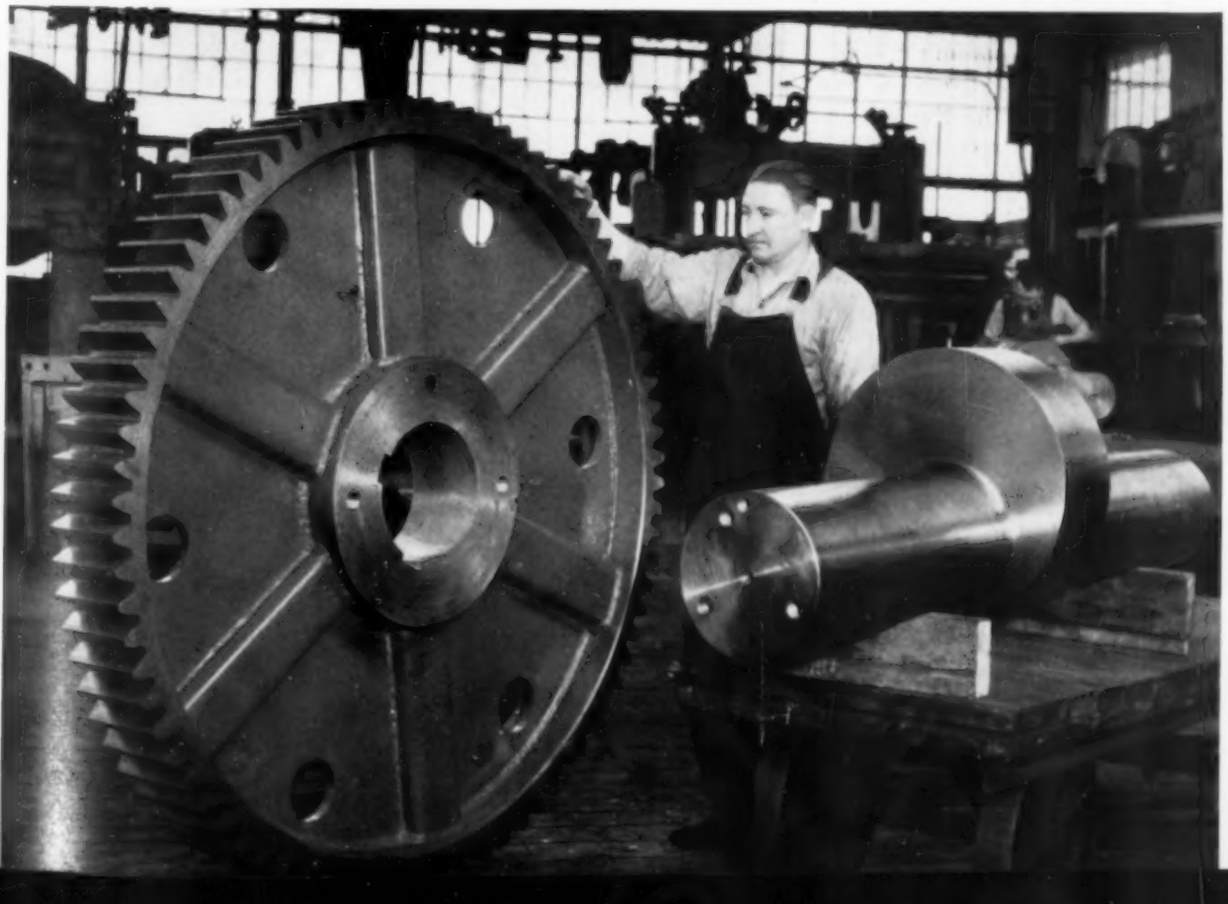
As a matter of auxiliary interest these large castings are made at Chambersburg in "concrete molds," a method outlined in a letter from Albert Portevin to METAL PROGRESS, September, 1932. According to Mr. Harrison this method has the following advantages: Less change in dimension in the mold due to weight of iron, less gas formed during pouring, fewer fins and cleaner surfaces and edges, hard spots practically eliminated, cheaper patterns, more rapid preparation of large molds.

Modern Forging Presses

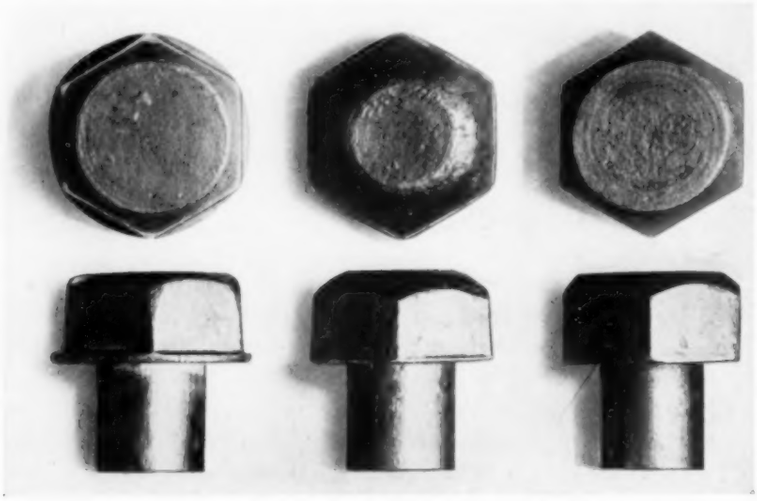
Recent trends in construction of machinery for press forging and for upset or machine forging are also described by J. H. Friedman in a paper for the forthcoming convention.

Press forging and upset forging (or machine forging) are essentially the same process. While the mechanical equipment is quite different in appearance, the respective machines use two classes of operations, *(a)* preliminary or gathering operations, and *(b)* final or finishing operations. The principal difference is that the forging press generally employs solid dies on both the anvil and the movable ram, whereas the forging machine uses split dies which are opened and closed in regular cycles to grip the stock against the action of the punch or die on the ram. A second distinction is that the stock for hot press forging is generally in the form of cut blanks or slugs, while the forging machine uses bar stock, cutting its own blank during the operation. The forging press will be considered first.

Minimum Elastic Action Under Working Forces Are Prime Requirements of Modern Forging Machinery. Welded gear and forged cam, photographed at Ajax Mfg. Co., are representative parts



Center Bolt, Upset in Cupped Heading Tool, Has Sharper Corners and Less Fin Than the One at Left Made in Old Style Forging Machine With Less Rigid Frame. Finished bolt at right has been restruck to remove fin and draft. Courtesy National Machinery Co.



Cold coining is still another type of work for finishing work cold, or very mildly heated, to dimension and parallelism ±0.005 in. or better. Obviously in this operation a very powerful machine must be used, in which "spring" has been reduced to the vanishing point. Development of this modern coining press, in Mr. Friedman's opinion, also resulted in a press forging machine that is ideal for hot work. He continues:

"Experience has proven conclusively that machine rigidity has a major effect upon metal flow. When a forging is produced in a press having a weak bed frame, which stretches under load during the final stage of the forging operation, the stock, following the path of least resistance, flows out between the faces of the dies in the form of a flash rather than into the die recesses. The result is a forging with an excessive amount of flash; and, at the same time, one which is not properly filled. The more complicated the die the less the chance of filling the forging. Setting the dies closer does not solve the problem, but merely results in additional 'springing' of the bed frame, and, if carried far enough, is likely to result in breakage.

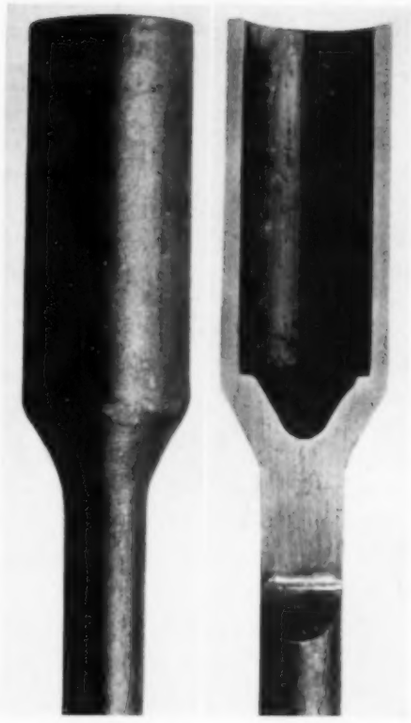
"The importance of machine rigidity and its effect upon metal flow was not fully appreciated until the demand for bolt headers and forging machines to handle alloy steels brought improvement in bed frame rigidity on that type of equipment. . . . There is considerable evidence in connection with the operation of drawing wire and similar work, and on hot and cold extrusion, which indicates that satisfactory results are obtained only so long as there is no appreciable reduction in working velocity. Evidently, once the metal starts to move, no trouble occurs if it is kept in rapid motion, but should the operation pause for any reason, it is generally found impossible to cause it to start again to flow. It has been observed that the gage on a hydraulic extruding press might drop from 300 tons at the beginning of an operation to 195 tons when the ram reached the mid-point of its travel, which would seem to be a paradox, but, if for any reason the movement of the ram was momentarily stopped, the full capacity of the 500-ton press would not

Forging Presses Are Usually Put to Making Comparatively Simple and Symmetrical Parts, Frequently After Rough Shaping Under a Hammer, Although Automobile Front Axles Are Being Made in Very Large Presses. Above are a few small examples, untrimmed, mostly three operation jobs. Mechanical ejection eliminates necessity for draft

be able to start it again.

"The point is, there is a great amount of evidence to prove the desirability of stiffness in equipment of this type, and none to disprove it. Granting that rigidity is essential in a good forging press, probably the next most important factor is speed. This matter of speed should not be confined to a fast revolving flywheel or a rapidly reciprocating ram. It should be considered in a much broader sense. Convenience and ease of feeding, quick starting, positive and rapid ejection are all vitally important factors of ultimate speed, and have their effect not only upon output, but upon die life as well. There is a constant flow of hot stock passing into the dies in a forging press which tends to draw the temper of the steel, thus causing the corners of the dies to break down prematurely. Consequently, if satisfactory die life is to be obtained, it is essential that contact of the hot stock with the dies be as short as possible.

"Summing up this matter of the essential features of a good forging press, it must be speedy, the entire machine must be rigid and free from spring, the die alignment must be accurate, the power of the dies should be ample and positive, it should be convenient and easy to feed, it should have instantaneous starting, and it must be provided with rugged and accurately timed knock-outs."



Automobile Drag Link Forging, Split to Show Deep Hole, Accurately Centered and Without Draft. A pioneering job that did much to establish the worth of heavy modern forging machines

Machine Forging

The ancient upsetting machines and bulldozers have undergone such pronounced changes in recent years that the old-time forgeman has difficulty in recognizing the modern open die, high duty forging machine. They are extremely massive, with mainframe a single steel casting, heat treated, and pre-stressed with heavy steel bars, shrunk in place. Innumerable mechanical features, adjustments, and improvements make for accuracy and long life. Increased depth of dies, wider die openings, and greater gathering capacity fit it for work which is limited mostly by the ability and ingenuity of the die designer. Jobs that were labeled stunts only a few years ago are now every-day performances. Again quoting from Mr. Friedman's ⊕ convention paper:

"An outstanding example of early pioneering is the automobile drag link forging shown alongside. Here is a forging which is impossible to make in any except the most modern high duty type machine. In fact, it was referred to by many experienced, old-time forgemen as a 'trick' forging and a job that certainly could not be economically made on a mass production basis. Another early job in this same category is a sleeve forging with a hole seven diameters deep. In spite of the dire predictions, however, both jobs were highly successful. The pierced drag link is still standard on practically all automobiles, well over 10,000,000 of them having been produced."

Where production is great enough an automatic feed may be utilized on these forging machines. Such equipment at the Ford Motor Co. was described in METAL PROGRESS, May 1934, and is shown on page 103. An ingenious device places the stock with a heated end into the first die at every other stroke of the ram, and then transfers the bars from die to die through the five operations necessary for its completion, thus keeping half the dies filled on each stroke, half of them cooling after contact with the hot metal. The automobile axle shaft shown in the inset is the type of forging so made.

Fiber Flow and Grain Size Control

Control of fiber flow has been a matter of importance ever since upset blanks have been machined into gears. Many detail drawings now show the pattern desirable in the part when it is sectioned and etched. Control of fiber flow, in the opinion of R. W. Thompson ⊕, writing in

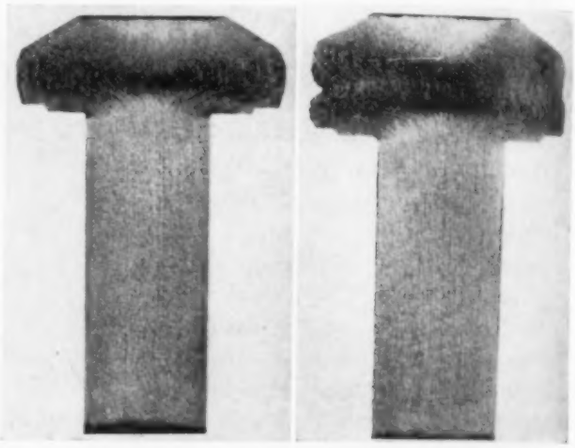
METAL PROGRESS last October, is the art of forging a billet so that the fiber in the original bar is left intact and unsheared.

In spite of its practical importance, little has been discovered about the fundamental nature of these flow lines, frequently called "fiber." It is usually assumed that the pickling acid eats out those portions of the steel surface that contain the segregated elements (either normal elements like carbon and manganese, or impurities like oxygen) which collect between the purer crystals during solidification of the ingot. The crystals in the ingot are arranged at random, so an ingot possesses no "fiber," but rolling and forging into rounds or bars extends the metal greatly in one direction, compressing it in two others, and this ranges the intercrystalline segregates in the longitudinal direction. Pickling will then eat them out and usually develop definite flow lines.

A somewhat vague relationship exists between such "fiber" and transverse weakness, so called. If test pieces are cut from a relatively fine-grained ingot, they will have approximately the same mechanical properties, irrespective of direction. But if the ingot has been forged down to, say, one fifth or less of its original cross-section, the test pieces cut longitudinally will be tougher (have better elongation and reduction in tension and absorb more energy in impact) than though they were cut transversely to the principal extension. This difference cannot be eliminated by practicable heat treatment, and on this basis the principal virtue of controlling flow lines is to place certain portions of the ingot in the desired region of the finished forging, and avoid unfavorable stress concentrations.

This common explanation of the nature of flow lines is almost too simple. It yet remains for someone to harmonize "fiber" with fracture appearance, austenitic grain size, and micro ghost lines, and to account for its variations melt to melt, or even in a single melt depending on the heating, rolling and forging program. The first informative work along this line was reported by F. W. Cederleaf and W. E. Sanders in METAL PROGRESS for July 1932. Their experiments on gear blanks indicated that a forging made in a powerful press so that the die is completely filled under uniform pressure will develop fiber on pickling much less easily than one that has not properly filled the die. The former forging they called a "dense" forging, and under the conditions they encountered, "dense" forgings cost considerably less to machine into gears and warped less in subsequent heat treatment.

These conclusions have not generally been accepted. Frederick G. Sefing in *Transactions*, December 1934, points out that shaping of larger pieces and of more varying thickness than gear blanks in the manner specified "would be a remarkable feat at any temperature in any forge shop." Mr. Sanders, in the same number



Cross-Sectioned and Pickled Forgings Show Lines Indicating Manner in Which Metal Flowed Into the Dies. Crinkly and folded flow lines must always be avoided

of *Transactions*, recommends forging 1% chromium steel transmission gear blanks (carbon 0.50%), from bars having coarse austenitic grain, inherent in the bar as received from the mill or induced by annealing. He recognized, however, that for carburized gears, the gear blank should be no coarser than grain size No. 5, so that the case may be refined by an ordinary treatment.

Grain size — inherent austenitic grain size — affects the behavior of steel in forging principally by virtue of its effect on the strength and plasticity at high temperatures. R. L. Wilson, trustee-elect, summarizes this matter clearly in METAL PROGRESS for August 1934:

"Whenever forgings are made of fine-grained steels and the forging temperature is not high enough to cause distinct coarsening of the structure, the fine-grained steels will not flow as easily as the coarse-grained steels, and more hammer blows may be required to finish the forging. In the case of forgings produced by the machine forging process, the displacement of metal must be completed in several forming operations, so that the greater strength of the fine-grained steels is manifested by the *power* required to make a forging.

"On the other hand, this very tenacity of the fine-grained steels enables them to withstand rapid large reductions in forging. Engineers who design machinery for the hot working of steels speak of a steel as having a certain deforming rate for a stated pressure. For the circumstances described, the fine-grained steels would be said to have a slower deforming rate at a definite temperature and pressure than the coarse-grained steels.

"Obviously, if the forging temperature exceeds the coarsening temperature, the grain growth of the fine-grained steels will confer upon them the same hot working qualities exhibited by the coarse-grained steels."

Temperature is another factor that is entirely under the control of the user of the forging machine. Generally the temperature is determined by the shape and character of the forging, the ease or difficulty in filling the die, the kind of alloy steel from which the forging is made, and the finish desired. If the forging has off-center lugs, undercut, crevices, or a large number of operations required to complete it, the temperature must be correspondingly higher. On the other hand, simple forgings like bolts and rivets can be made at low temperatures. Most steels scale rapidly above 1500° F., and consequently, other things being equal, it is desirable to forge at a temperature at or below this point. Proper furnace design and control of atmosphere will, of course, assist in the reduction of scale.

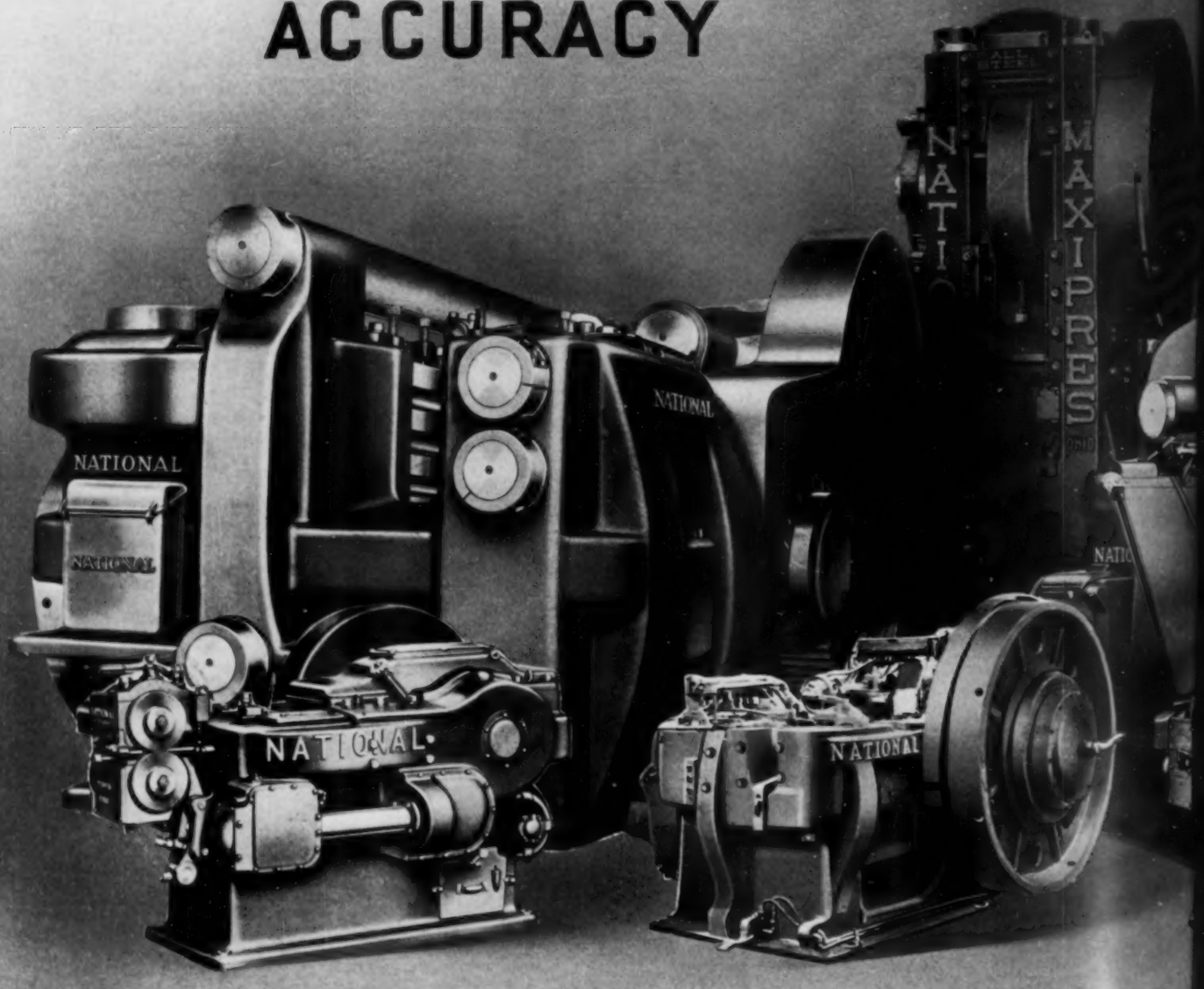
Some valuable hints along this line are contained in new recommended practices contained in the ⚙ 1936 *(Cont. on page 106)*

Blanks for Ford Rear Axles Are Heated on One End in Furnace on Balcony at Right, and Conveyed to Automatic Feeder in Front of Forging Machine. Feeder transfers stock from die to die so that dies are working every time machine closes. Finished job is shown in inset at left. This and other methods of fast forging were described in Metal Progress for May, 1934

BUY NATIONAL FOR

for

RANGE
CAPACITY
SPEED
ACCURACY



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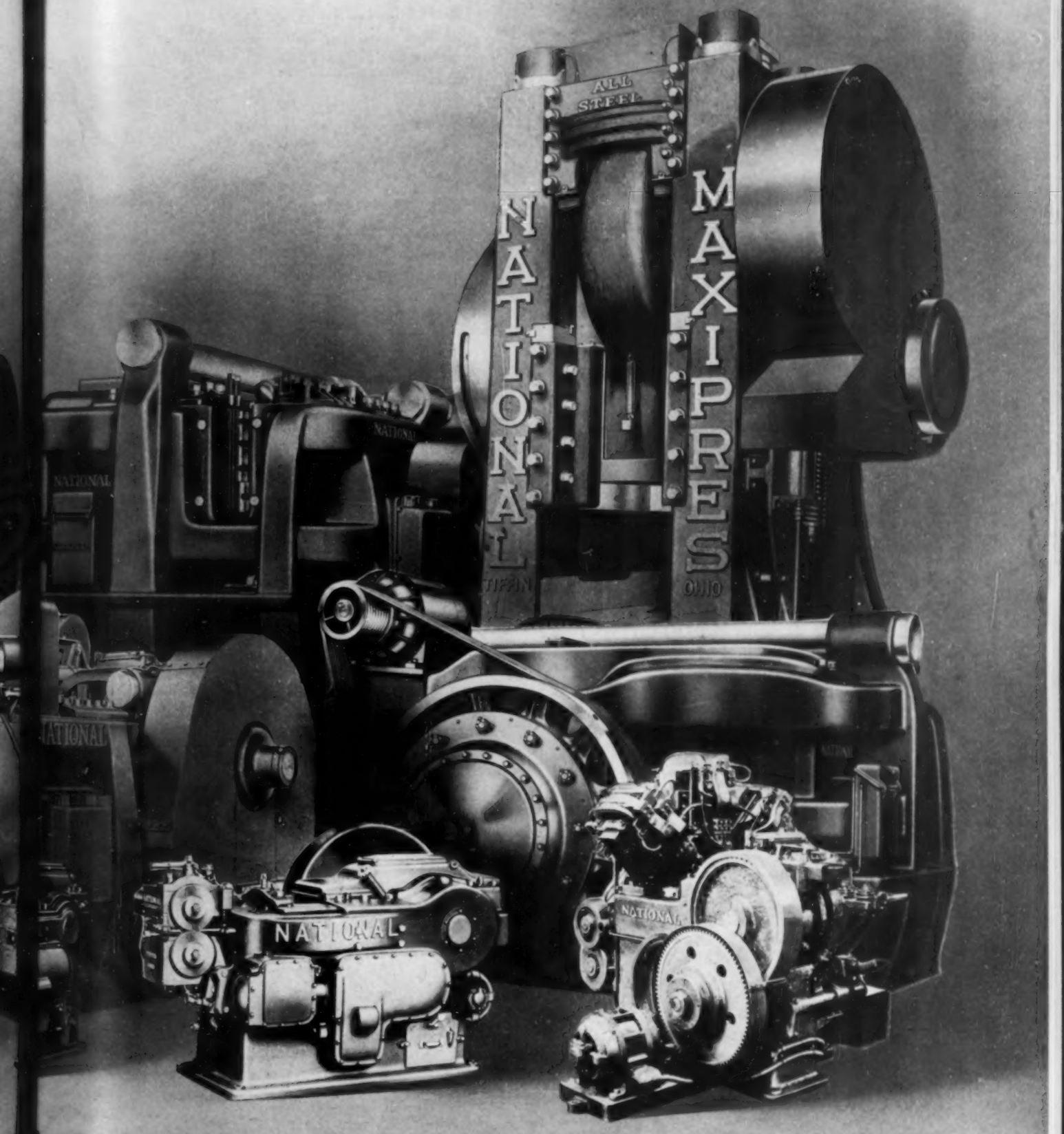


MACHINERY CO.

OHIO

Chicago

Forging

(Continued from page 103)

Metals Handbook. Common practice in heating carbon steel, less than 0.50% carbon and up to 3 in. square, is at the maximum rate of 5 min. per in.; however some metallurgists require slower rates. High carbon and tool steel should be preheated to 1350° F.

Recommended Forging Temperatures (Maximum)

Carbon	Carbon Steels	S.A.E. Alloy Steels
0.10%	2400° F.	2350° F.
0.20%	....	2300
0.30%	2350	2250
0.40%	....	2250
0.50%	2300	2200
0.60%	....	2200
0.70%	2225	
0.90%	2150	
1.10%	2075	
1.50%	1900	

Alloy steels of the common S.A.E. specifications should be heated no faster than half the rate specified above. Finish forging temperatures should be no lower than 1800° F. Slow and uniform cooling from the forging heat, *down to below* 400° F., is advisable in all forgings larger than 3 in. in thickness in order to avoid the development of flakes and internal ruptures. After this first cooling, the forging can be safely heat treated.

Extrusion

An account of the extrusion of the commercial non-ferrous metals, either hot or cold, has been prepared by D. K. Crampton for the forthcoming convention. This comprehensive paper not only describes the equipment available and its operation, but the suitable alloys and their properties. The scope of the process may be appreciated by a list of its principal applications to various metals and alloys:

Lead: Telephone and power cable sheathing; pipe; rubber hose encasings prior to vulcanizing; moldings.

Tin: Solder wire (solid or flux-cored); ornamental moldings or mounts; collapsible tubes.

Copper: Tubes, bars and slabs for rolling; finished rods; intricate shapes and moldings.

Aluminum: Same as listed for copper; structural shapes; thin-walled collapsible tubes.

Magnesium: Structural shapes.

Zinc: Rod and shapes for draw bench work.

Nickel: Tubing.

An extremely large tonnage of copper-base alloys is extruded, mostly in hydraulic presses. Tube presses up to 4500-ton capacity and rod presses up to 3500-ton are in use. They comprise two cylinders, strongly tied together; one is the hydraulic cylinder wherein a piston is forced forward. The front end of the piston rod fits the second cylinder tightly, into which a cast billet of the metal has been placed and the front end closed by a massive die. Movement of the piston forward "squirts" the metal out through the opening in the die, and a rod, tube or shape of proper cross-section is the result.

Mr. Crampton finds that hydraulic accumulators are seldom used with rod presses, for the rod alloys can be extruded slowly enough to operate the presses directly from pumps; on the other hand, many of the newer alloys for condenser tubes are best extruded very rapidly, and this is possible only when an accumulator is available to fill the hydraulic cylinder.

Linear speed of extrusion of the various copper alloys varies greatly, depending on the composition, temperature, and size and shape of the section. Speeds all the way from 20 to 500 ft. per min. are commercial; the latter figure may sometimes be doubled if adequate accumulator capacity is installed.

Pressure also varies, depending on the above-mentioned circumstances. In the author's words: "The pressure required to extrude also varies quite widely depending on much the same factors as those which control speed. With the softer alloys, larger sizes, and simpler shapes, pressures as low as approximately 30,000 psi. might be used. With harder alloys, more complex shapes and relatively smaller sections, pressures up to 120,000 psi. are found necessary. In general, when the press is operated direct from the pumps, the pressure required to start flow through the die is fairly high. Immediately after starting the pressure falls to a fairly low figure which holds relatively constant until near the end of the extrusion when the pressure may rise to at least double that required for starting."

"Hooker Process" and impact extrusion differ essentially from the above in that small metal slugs at room temperature are fed into a high speed crank press. A button of soft metal may be squeezed into such a thing as a toothpaste tube at a single blow; harder metals like brass require about four steps to form into a cartridge case. In the latter class of work, tool pressures are especially high, and the problem of long-lived dies is always present. Temperature rise is prevented by the fact that all the working requires a small fraction of a second; velocities may be as high as 2000 ft. per min.

Cold Drawn Bars

expanding in Utility

Inspecting Ground Drill Rod

Photo by Margaret Bourke-White for Ludlum Steel Co.

SEVERAL valuable papers concerning cold-drawn bars have appeared in a continuing series in ⊜ publications, including those ready for publication in the new Handbook and for consideration in the symposium at the October convention. These concern not only the problem of steel mill practice for improved quality, but also fundamental studies on the nature of machinability and drawability.

As is well known, cold-drawn bars are made from hot-rolled rods, pickled, limed and pulled cold through a die of appropriate shape to reduce the dimensions about 1/16 in. on the diameter or thickness. The fine reputation of this class of goods is due in no small measure to the fact that the hot-rolled rods at the start must be sound and uniform. Externally the principal effect of the cold draw is a vast improvement in surface smoothness and size accuracy. Internally the most apparent effect is a large increase in the elastic ratio (yield point divided by ultimate strength), a decrease in elongation and a hardening.

A less easily measured effect of the cold drawing process is a pronounced improvement in machinability. Quoting J. E. Beck ⊜, metallurgical engineer, Jones & Laughlin Steel Corp., in his article on Cold Forming Processes for the 1936 convention, "Aside from inherent machining quality, the cold-drawn bar product with its close size and section accuracy, freedom from scale and better straightness offers sufficient machining advantage over hot-rolled material, to make it preferable and in most cases more economical than the lower priced hot-rolled stock where ease of machining is a factor. In support of this statement is the steady demand for cold-drawn material in the face of serious attempts to accommodate hot-rolled material in the interest of lowering raw material costs."

A very large amount of work has been done on the study of machinability, especially of screw stock — that is, cold-drawn, high sulphur, low carbon steel, usually made in the bessemer converter. H. W. Graham ⊜, general metallurgist of Jones & Laughlin Steel Corp., has told

the story before several Chapters of a 15-year investigation which shed much light on the metallurgy of the steel manufacturing process. In his opinion, the ideal steel for machinability is one which is soft and rather brittle, and yet does not work harden during rapid shearing under compressive loads (that is to say, cutting). High sulphur bessemer steel is soft and brittle, but *does* work harden, and to wide degrees, heat to heat, and in this respect is capable of improvement.

For instance, if the work hardenability is measured by change in impact and hardness after 6% reduction by cold drawing, one heat (rather insensitive to work hardening) might lose one third its toughness and gain 25 points in Brinell hardness. An average heat might lose half its impact value and gain 35 points in hardness, whereas in an unusually "sensitive" heat the toughness might fall to 5% its original value and the hardness increase 60 Brinell numbers. These "sensitive" heats also are the ones which age harden (a matter somewhat extensively discussed in the next article).

While coarse grain will enhance the machinability, it is not the whole story. At any rate, Mr. Graham says that the characteristics of bessemer steels can now be determined before final rolling, drawing, and shipment, and the customer can be assured of metal selected to meet his particular requirements. Machinability of such selected shipments, as measured by tool life in a screw machine, has been improved, even as much as 100% in extreme cases.

Extra machinability has also been provided by a higher sulphur steel containing more inclusions, without, it is said, harming the tensile, torsion, and transverse impact values. There are also large quantities of free-cutting steels of the S.A.E. 1300 classification, much higher in manganese than screw stock.

Machining Low Sulphur Steels

J. D. Armour, metallurgist of Union Drawn Steel Co., has discussed briefly the problem of increasing the machinability of the low sulphur steels, both plain carbon and alloy. Low sulphur steels at best will not machine anything like the high sulphur types, he writes in METAL PROGRESS, May, 1935, but nevertheless there is much that can be done to improve their machining properties. If the steel is low in carbon and "drags" in machining because it is too soft, it can be cold drawn a proper amount to reduce the ductility to the point where it will machine much more satisfactorily.

Generally speaking, a discontinuous structure makes for good machinability. For example, ferrite containing carbides or manganese sulphide, gray iron containing graphite flakes, alpha brass with lead, and aluminum alloys with lead.

On the other hand, with the higher carbon steels (say 0.40) the best line of attack is to heat treat to the correct type of structure. He has found that a clear-cut structure with ferrite and pearlite cleanly separated, and with the pearlite distinctly lamellar, is very suitable for automatic screw machine work on the straight carbon steels. In the alloy steel lamellar pearlite with just a suggestion of spheroidization seems to machine a little better. When carbon reaches about 0.50% in some of the alloy steels and over about 0.60% in the straight carbon steels, a spheroidized structure machines very well on automatic screw machines, but would not be so good for gear cutting or broaching.

Heat Treating Problems

Heat treatment brings up another problem. Mr. Beck reports that annealing or normalizing is quite uncommon for the stock for cold-drawn bars of mild steel except when specified by a purchaser or necessary because of the required properties. However, in carbon steels over 0.50% carbon, it is almost necessary to anneal before cold drawing to minimize breakage in process and improve the ductility of the product.

"Within the last few years, some advantage is realized in special instances by low temperature treatments after cold drawing. 'Strain drawing' at temperatures in the neighborhood of 400 to 700° F. is employed for 'accelerated aging.' On the other hand, improved ductility without appreciable losses in tensile and yield values is produced by tempering between 700 and 1000° F."

The above is aside from a very interesting development of the recent years which has so many advantages it will not soon be abandoned. The latter refers to the production of special sections in any of the engineering alloys, properly heat treated in the mill so that only the simplest machining operations are required to make a part for subassembly. Relatively small lots of such sections can be produced much more economically by cold drawing than by any other means, as it costs less *(Continued on page 124)*

Advances in Sheet Steel of prime Importance

A Summary of Important ASM Articles

By the Editor

A Glimpse of the Continuous Train of Four-High Stands in the New Sheet Mill, Youngstown Sheet and Tube Co.

STATISTICIANS in the steel industry have all been impressed by the increased importance of thin plate, sheet and wire. No longer ago than 1922 sheet, strip and tinplate combined accounted for 28½% of the total steel production, and this stayed at 26½% in 1931 (a depression year); yet these three grew to no less than 43½% in 1935. Sheets are now, and have been yearly since 1932, the most important class of output in point of tonnage. This reflects not only the growing importance of automobile bodies, refrigerator cabinets and metal containers, but also the trend in the manufacture of minor parts, stamped, pressed and welded of thin stock.

Preceding and accompanying this has been the marvelous development of continuous sheet mills. Introduced 14 years ago, the industry has invested about 250 million dollars in such plant. In the same 14 years the average price of steel sheets has been reduced 48.6% (according to D. Eppelsheimer, vice-president of American Rolling Mill Co.). Here, economists might well point out the relationship between lowered prices and increased consumption; metallurgists and production men will insist that the ability to produce wider and wider sheets of excellent surface and forming properties, and the simultaneous development of improved presses, welders and lacquers have done much to increase the market.

At any rate, the principal recent construction in American steel plants has been of continuous sheet mills. Within a year enormous new mills have been completed by Youngstown Sheet & Tube Co., Bethlehem Steel Co., Ford Motor Co., and U. S. Steel Corp., and one of the earliest ones (American Rolling Mill Co.) rebuilt for a wider product.

Quoting from Walter Mathesius, Manager of Operations, Carnegie-Illinois Steel Corp., in METAL PROGRESS, Oct. 1935, "I should like to give credit especially to the automotive industry for having been among the first of the major steel users to recognize the inherent deficiencies in the older methods of dealing in

rigid and detailed specifications and for having lent a capable and helping hand to bring about the more direct contact and understanding of technical requirements, which has enabled the steel industry to satisfy the exacting and often rapidly changing demands of the motor world.

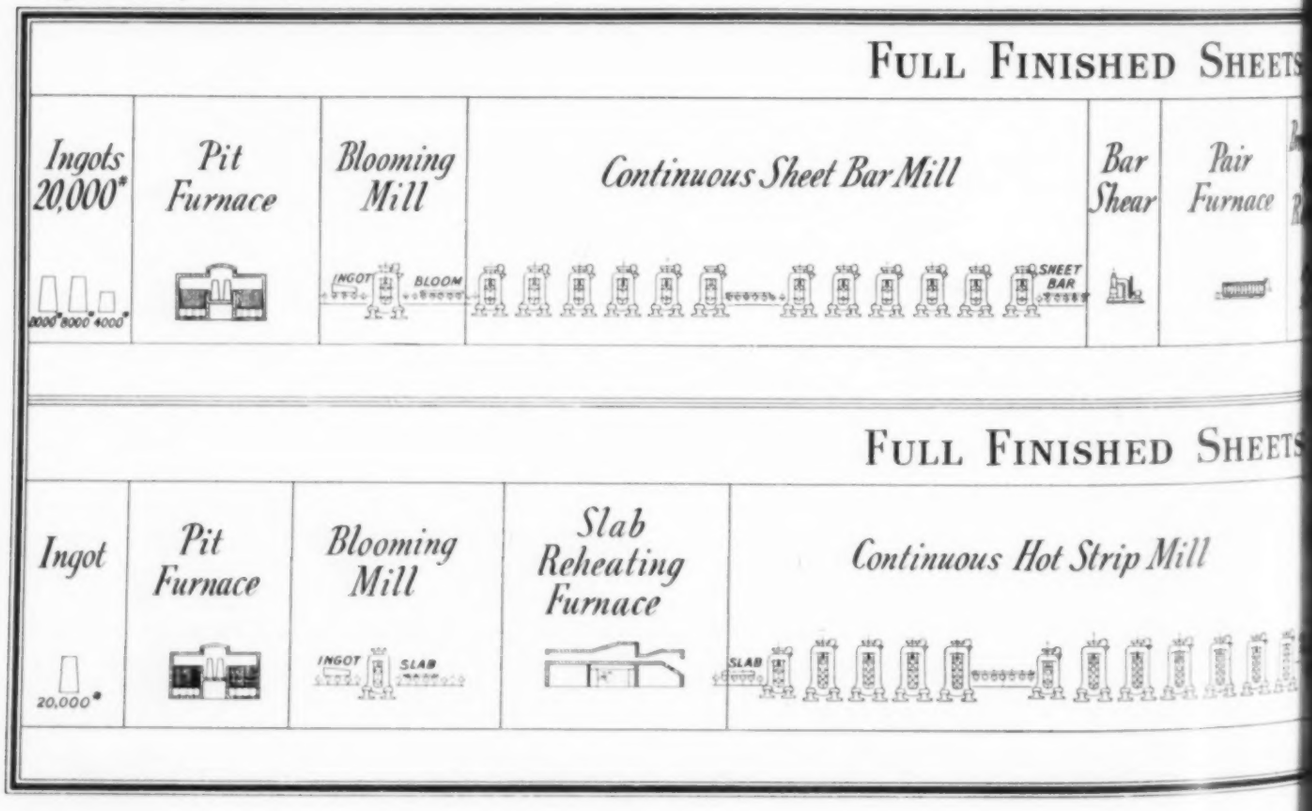
"Many examples may be selected to illustrate this principle; for instance, 'ordinary' low and medium carbon steels in the form of plates, sheets and strip, suitable for severe cold forming operations. Frequently other fabricating requirements such as welding, enameling or galvanizing, or other desired properties like corrosion resistance, non-aging and high strength characteristics add zest to the game and challenge the ingenuity of the producer. Here each new design of parts, each new forming process, may it involve automobile brake drums, fenders, and chassis frames, or furniture, grave vaults, and corrugated culverts, or hydraulic pen-stocks and welded pressure vessels may require individual study for each step of production from blast furnace to surface inspection.

"For many years a normal, well-made, semi-killed steel, containing small amounts of silicon, answered most of the requirements of low carbon sheets and strip steels. But as forming practices became more drastic and three-step deep drawing went to two-step and single operations, greater ductility and greater uniformity were demanded than could be produced in this steel.

"Rimmed steels became the vogue with little, if any, change in chemistry, but with a decided improvement in ductility and lower work hardening effect. It soon became apparent, however, that this type was not the panacea which the sheet mill and its customers were seeking. Due to its inherent nature, related to the deliberately promoted selective freezing process of the steel in the ingot molds and its typical array of blow-holes, it has caused troubles through non-uniformity of properties between different sections of product, corresponding to the inner and outer portions of the ingot as cast. The blow-holes gave rise to blisters in pickling, and matters grew worse when certain welding practices and enameling processes had to be considered, not to mention the serious complications which arose from the age hardening tendencies of the rimmed steels.

"As a result we find another instance where the steel producers and their metallurgists took the lead and succeeded in developing a series of thoroughly killed, fine-grained, aluminum treated steels, which give great promise of a decided step ahead, since they combine in a

Diagrams Courtesy Bethlehem Steel Co.

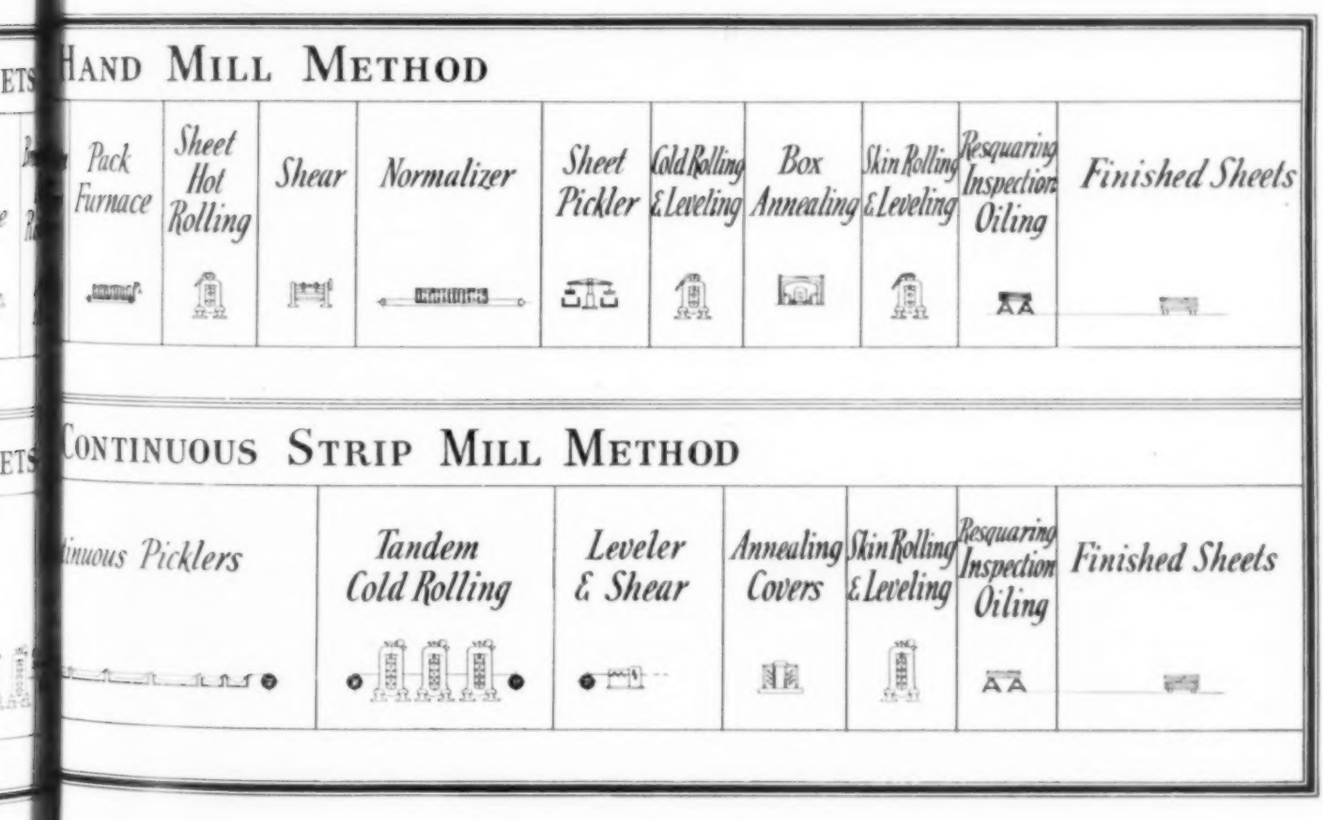


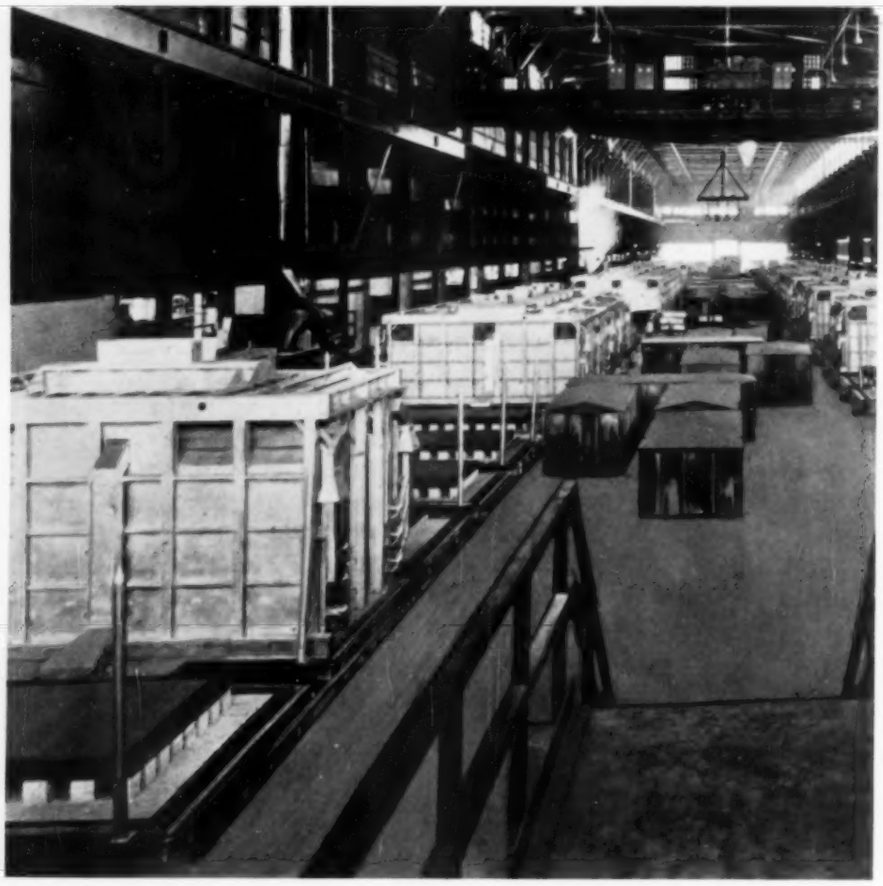
large measure the desirable properties of the rimmed and the silicon-killed types, without inheriting their principal limitations."

Changes in Annealing Practice

Aside from these changes in furnace and rolling practice a most interesting pendulum swing has occurred in the annealing department. When, in 1920, a sedan door was welded from five small pieces, one box anneal was usually sufficient. Two box anneals, one comparatively high (about 1500° F.) and the other lower, with time cycles left to the annealer's judgment, were sufficient to make steel for any part. When one-piece front fenders and radiator shells came in (1925 or 1926), something better had to be done, and an "open anneal" or normalizing treatment was substituted for the first box anneal. This gave a harder yet tougher sheet, and minimized the difference in directional properties. With passage of years even these practices reached their limit in supplying customer demands. We now find time-temperature control extending clear back to the heating furnaces and for the slabs at the entrance of the mills. Standardized speed of rolling and control of drafts produce a coil of hot sheet-strip at the end having correct grain size and a minimum of rolling strains. This material, still in coils, is pickled and cold rolled to proper gage, sheared to sizes and box annealed, after which it is given a light "skin roll" for surface finish. The diagrams below, reproduced by courtesy of Bethlehem Steel Co., indicate not only the essentials of the most modern practice, but also contrast them with the more numerous operations for full finished sheets as made in the older hand mills.

Steel treaters will notice that the swing in these 15 years has been from box annealing to continuous normalizing, and back again to box annealing. But the metal is vastly different and the box annealers equally improved in construction and operation. Instead of heavy cast steel covers, heated slowly in fuel-fired furnaces of low thermal efficiency and inadequate temperature control, we now see sheets piled on a permanent base, at least three pyrometer couples inserted at governing points, and the whole pile covered with a thin metal housing, sand sealed at bottom and filled with prepared gas of non-oxidizing characteristics. Over all this is then placed a movable heating oven, well braced, insulated, and heated economically either with electric resistors or radiant tubes, gas fired. Every pile is individually controlled in its time-temperature cycle according to specifications is-





Thirty Annealing Furnaces (Removable Units) and Four Times as Many Bases and Inner Covers for Annealing Sheet Steel in Controlled Atmosphere; Lackawanna Sheet Mill, Bethlehem Steel Co.

sued by the metallurgical department, devised to meet the particular duty intended. Conditions inside the pile are accurately known at corners, edges and center, to make sure that specified conditions actually exist in the work under treatment.

Aging of Steel Sheet

It is one thing to make steel sheet to exacting specifications and capable of severe drawing and forming operations, but another to insure that these qualities do not change materially before the customer's fabrication operations are completed. It has long been known that low carbon steel sheet gradually changes in ductility and hardness (and therefore workability) after any heating and cooling cycle except the slowest, and after any cold working, such as rolling or even roller leveling. True enough these changes are often small in amount, yet as specifications were constantly narrowed in acceptance limits, it became necessary to bring these matters under control. This has involved much study of fundamentals, and some important results have been published.

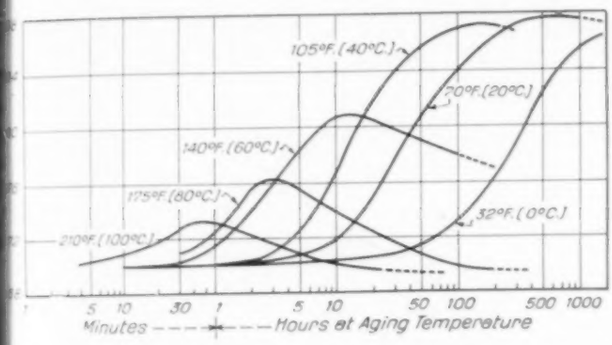
The whole problem of aging of steel was discussed in *Transactions* last December by E. S. Davenport and E. C. Bain, research metallurgist and assistant to vice-president, respectively, U. S. Steel Corp. Its complexity was materially reduced by these investigators, who clearly distinguished between two different varieties of aging superposed in low carbon steel. The first is observed in annealed wire and sheet which may have possessed a low hardness value and high ductility immediately after annealing, but which, after a few weeks' storage, is found to have become harder and to have lost some of its ductility. The second is a change in properties after rolling, drawing, bending, and so on. Both of these changes occur at room temperature, and more rapidly at slightly higher temperature. Each one has a particular "pattern" of time-temperature-rate curves, as shown by the upper figure on the opposite page for the first or "quench aging" phenomenon and the lower figure for the second or "strain aging" phenomenon.

The first pattern parallels in all essentials the familiar precipitation hardening of duralumin. It is generally agreed that in this case rapid cooling from some high temperature produces a supersaturated solid solution, and at lower temperatures a shower of particles develops with time, well distributed within the grains of solute metal, thus hardening them by slip interference. According to the latest studies on the solubility of carbon in alpha iron, sketched on page 122, a steel fairly rapidly cooled from 1250 to 1450° F. would contain about 0.03% carbon in solution in ferrite, three-quarters of which would tend to separate at atmospheric and slightly elevated temperatures — up to 900° F.

Minor quantities of the other elements might also act in a similar way and therefore be responsible for this change, but that it is carbon rather than oxygen or hydrogen is indicated by the fact that carbon-free electrolytic iron (either saturated with oxygen or purified by hydrogen) changes in hardness very little with time, whereas a 0.05% carbon steel containing

0.27% aluminum and no more than 0.002% oxygen quench ages strongly. Nitrogen may also be in part responsible, by a mechanism exactly similar to that postulated for carbon.

At any rate, Messrs. Davenport and Bain are able to remove the effect of such quench aging by reheating to a temperature of say 210° F. for the proper time. It takes 24 hr. to reject all the dissolved carbon from the supersaturated solid solution at this temperature and to enable these rejected particles to accumulate in a relatively few regions where their effect is innocuous. By this simple and inexpensive method, low carbon sheet steel may be put into a permanent state which will not harden substantially thereafter by aging at any temperature lower than the preliminary treating temperature (in this case 210° F.) — as long as it is not cold worked.



Above—Quench Aging of Basic Openhearth Rimming Steel. Sheet quenched from 1325°F. and held as indicated. Analysis: C 0.06%, Mn 0.40%, Si 0.009%, P 0.12%, S 0.031%, O_2 0.020%, N_2 0.0042% (*Davenport and Bain*)

At Right — Strain Aging of Cold-Rolled, Basic Openhearth, Rimming Steel. Upper block: Cold rolled after preliminary aging at 212° F. to eliminate effect of gradual carbon precipitation. Lower block: No special heat treatment before cold rolling. Analysis: C 0.04%, Mn 0.16%, P 0.012%, S 0.032%, O_2 0.025%, N_2 0.0034%

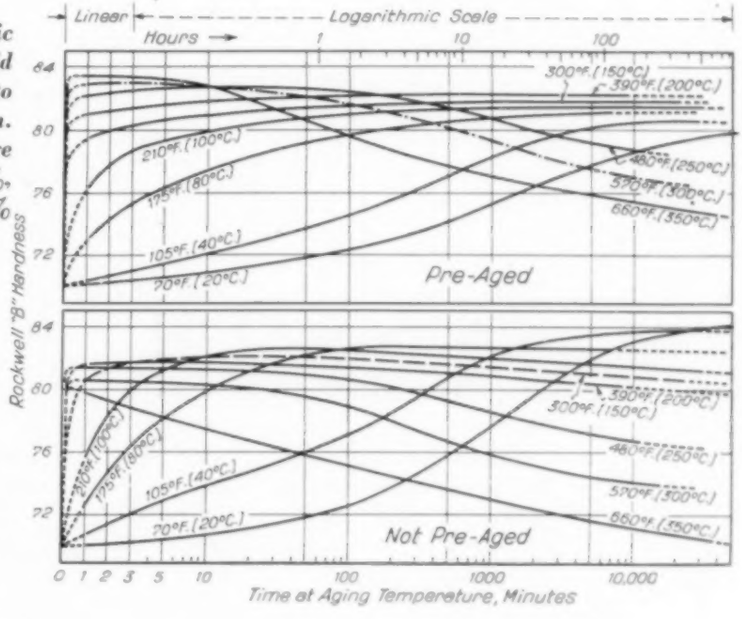
Hardening by Cold Work

Now to determine some facts about the gradual hardening when a cold-worked sheet is stored.

A preliminary treatment for stabilizing the carbon was imposed by Messrs. Davenport and Bain on the samples which, after cold working, produced the curves in the block at right: the effects recorded (due to "strain aging") are entirely aside from the quench aging caused by carbon. The outstanding characteristic of this new pattern is the rapidity with which maximum hardness is achieved when moderately hot (660° F.); in fact, it suggests that the so-called "blue brittleness" noted at that same temperature region is due to this cause.

Even the older textbooks and other treatises on soft steel point out that in the temperature range above about 300° F. cold work produces a much greater hardening effect than the same degree of deformation on the same soft steel at ordinary room temperature. Since the hardening in strain aging is due to two factors, *(a)* deformation by plastic flow, forming slip bands, and *(b)* suitable time at aging temperature, it is clear that when deformation occurs *at* proper aging temperatures near the blue heat range, the precipitation of the hardening constituent during stage *(b)* occurs almost immediately after stage *(a)*. In successive passes the metal becomes very hard and the reduction in thickness is accomplished only by considerably increased roll pressure. If the metal is kept below the aging temperature, lower roll pressure suffices to effect even greater deformation, and this relationship is useful in working out rolling schedules for maximum effect with a minimum of power expended.

[These researches also suggest to the Editor that the hardening which occurs during cold work generally, in metals not ordinarily thought of as age hardening, may also be largely due to almost instantaneous formation of hardening



compounds in the mobile metal at slip planes, rather than the creation of amorphous metal along the same surfaces.

Thus, metals of greatest purity generally exhibit astonishing ductility and ability for cold deformation without requiring intermediate process anneals. Yet a piece of spectroscopically pure copper wire should develop the same amount of "amorphous" metal — postulated to be comparatively hard and unyielding — in drawing 90%, say, as an equivalent sample of tough pitch copper drawn the same way. Electrolytic tough pitch copper, though quite pure, still must have a multitude of stranger atoms such as much oxygen distributed throughout the copper. Even though they are incapable of diffusion and accumulation at ordinary temperatures, and thus cannot cause precipitation hardening, they may be mechanically brought into juxtaposition with others in mobile metal during plastic flow, and thus be able to form compound entities large and numerous enough to act as keys on these planes and thus interfere with further slip.]

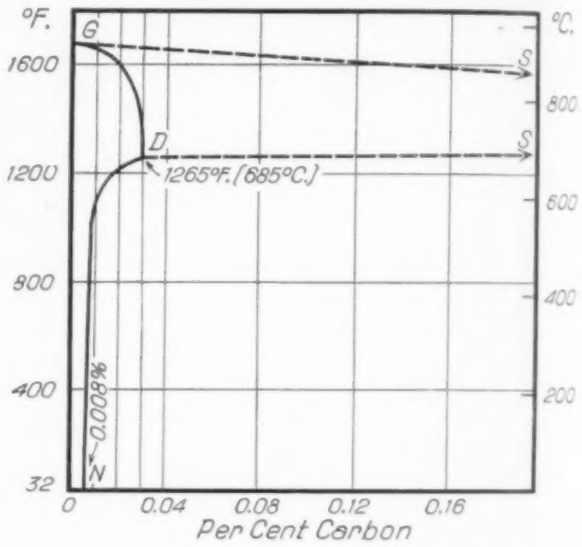
At any rate the whole course of the curves on page 121 representing strain aging, suggests a peculiar type of precipitation reaction which occurs at a high rate (rapid hardening) but produces a molecule that diffuses and agglomerates slowly (slow subsequent softening).

Iron oxide is a compound that, theoretically, should act in this way. It is also significant that the so-called "non-aging" steels now on the market are manufactured in such a way as to reduce the dissolvable oxygen to vanishingly low concentration. Likewise a carbon-free, high oxygen electrolytic iron will age after strain almost as much as a rimming steel, whereas the hydrogen-purified iron and the low carbon steel with 0.27% aluminum are fairly stable in hardness during the same treatments. The conclusion is therefore that an iron pre-aged for 24 hr. at about boiling water (to precipitate the inevitable carbon) will not harden after cold rolling if it has practically no free oxygen — that is to say, made of steel dead melted and well deoxidized by aluminum or its equivalent.

Anson Hayes, R. L. Kenyon and their associates at American Rolling Mill Co. have published several articles about the characteristics of steels that are stable against strain aging, and proof against "stretcher strains." In general, they harmonize with the other facts presented in this article. That company has also advertised its ability to produce stabilized sheet commercially, which after the correct amount of cold work, will not re-acquire the faculty of stretcher straining, at least for several months. Unfortunately, no information as to its method of manufacture has been made public.

Stretcher Strains and Allied Defects

Interesting though these speculations may be, and important though it is to produce a sheet that will not change in ductility with age (and thus in its drawability before cracking) another class of manufacturing troubles plagues the maker of deep drawn steel articles. In the shop they are known as "stretcher strains." Laboratory researchers have identified them with Lüder's lines, Hartmann lines and the Piobert effect. The upper figure on the opposite page shows a portion of a stamping infested with them; obviously if a smooth finish is required on the completed article very expensive grinding is in order. "Kinks," "breaks" or "flutes" are defects of similar origin — merely localized stretcher strains occurring during handling or even roller leveling.

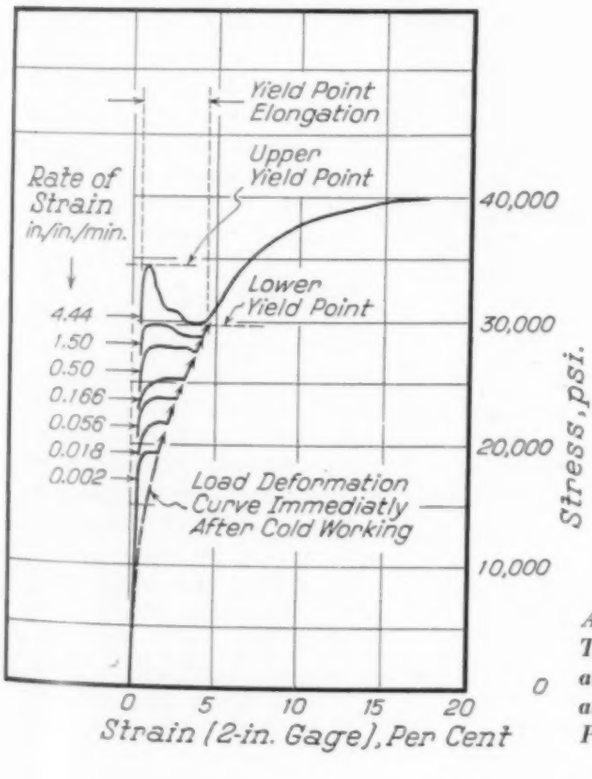


Region G-D-N-O-G Represents Solubility Limits of Carbon in Alpha Iron or Ferrite, According to J. H. Whiteley, Journal of Iron & Steel Institute, 1936. A low carbon steel will retain considerable supersaturated ferrite if cooled reasonably fast through the range 1600 to 1200° F., and this precipitates in time, gradually changing the hardness and drawability

Joseph Winlock and his associates at Edward G. Budd Mfg. Co. have published a long series of researches on this problem in *Trans-*

actions, the latest (with R. W. E. Leiter ⊜) in preprint form for the forthcoming convention. These metallurgists agree with others that stretcher strains occur while the metal is undergoing the yield point elongation (noted in the diagram at bottom of the page.) In a testing machine running at normal speed (on the same order as that of pressing operations) the transition from elastic to plastic state occurs in the specimen first at some localized region, and the load remains constant while local slipping and work-strengthening continue to spread throughout the entire specimen. These regions of localized elongation comprise stretcher strains; their depth is proportional to this elongation at the yield point. (Some European investigators have questioned whether the load can actually *decrease*. Some unusual stress-strain curves are doubtless characteristic of the machine rather than of the metal being tested, but the autographic machines of all sorts do not manufacture a pronounced yield range, unique in low carbon steel, out of nothing.)

Messrs. Winlock and Leiter have constructed a tensile testing machine which has a controllable rate of strain and find that the elastic limit of commercial steel sheet, freshly annealed, is lower as the rate of strain approaches zero. This is also true of the amount of yield point elongation, so that a series of superimposed curves (as shown) will trace an inner line which coincides closely with the load-deformation curve of the same metal taken immediately after being put through a roller leveler (the shop method of placing sheet in the plastic condition, immune to stretcher strains).



A Series of Load-Deformation Curves for 0.036-In. Sheet Traced Automatically at Different Rates of Strain (Winlock and Leiter). 0.05% carbon steel, made in hand mill, box annealed. Coarse grained: 20 grains per sq. in. at 100 dia. Pieces furnace cooled from 1250° F. anneal in sealed box

Stamping With Stretcher Strains (Winlock and Leiter)

Other relationships discovered are that the elastic limit and the yield point elongation for a given rate of deformation (and the amount of preliminary cold work necessary to avoid stretcher strains without hardening the metal) decrease as the size of the ferrite grains is made larger. Practically, however, grain size cannot be too great without developing "orange peel." A useful compromise is a uniform structure of about 85 grains per sq.in. at 100 dia.

On the other hand, the tensile strength is relatively unaffected by speed of deformation, so that conditions of slow speed and coarse grain may be established where a low elastic ratio exists — an important matter in deep drawing, else smaller sections could not transfer stress enough to deform the succeeding larger sections.

Cold-Drawn

(Continued from page 116)

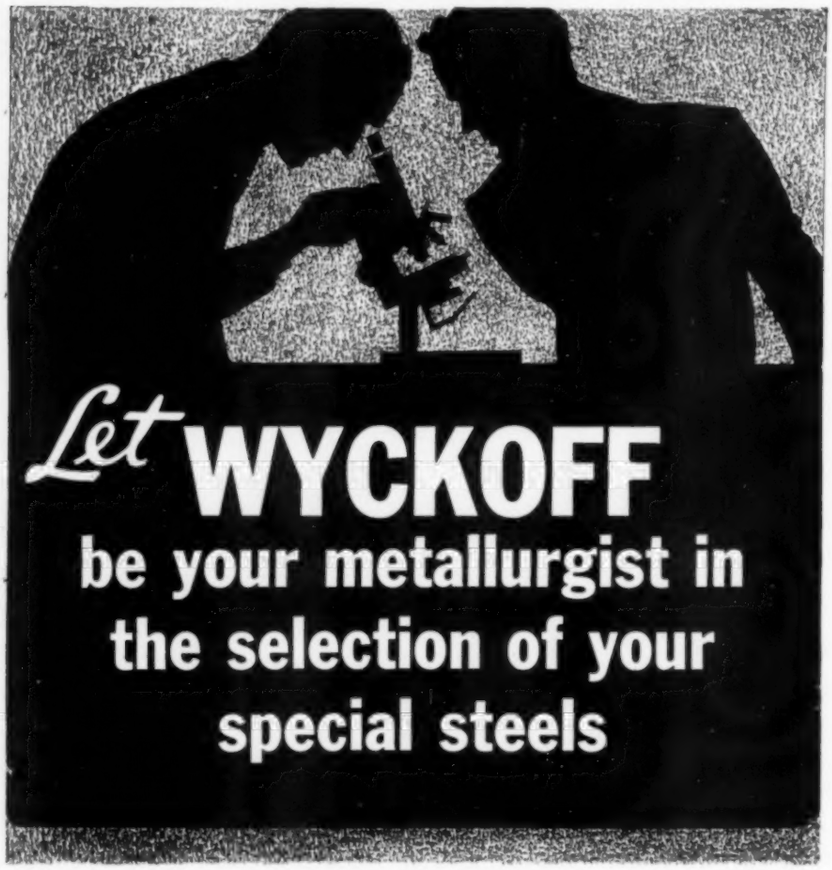
to make the necessary series of dies and mount them on a draw bench than it does to turn a set of rolls and mount them in a mill. Ordinarily a round or flat bar would be hot rolled to a roughly similar contour in a small hand mill, and then reduced to exact size and shape in from one to six dies, depending on its complexity. Finally, the entire lot may be heat treated in controlled atmospheres at the source, thus avoiding expensive equipment in the fabricator's shop.

One of the most important uses of cold drawn products is for cold heading into bolts, rivets, and many products that have small resemblance to these more common forms. (This field is adequately described by Roy H. Smith, ⓜ, vice-president, Lamson & Sessions Co., in his paper "Cold Heading" for the 1936 convention.) Economical operation depends on a number of properties, often of conflicting nature, in all varieties of plain and alloy steels up to 0.50% carbon.

One of the important features is the surface coating. A good coat is necessary to facilitate drawing through a die, but some upsetting operations are so severe that an even more tenacious coating is necessary to prevent the rod from seizing and galling the heading dies. As pointed out by Mr. Graham, the manufacture of bolts involves diametrically opposing requirements in the two essential operations: For best cold heading the steel must be soft and plastic; for best machining, soft and brittle. Obviously, a compromise must be struck.

Bolt heading wire is usually made of rimming openhearth steel and therefore produces rod having a softer and more plastic surface. Up to a few years ago, bolt makers specified low carbon steels (0.06 to 0.12%) but more recently it has been found that higher carbon steels can also be used without undue wear on the dies if, during its manufacture, the rod is heated above the critical for grain growth.

In the harder steels (from 0.30 to 0.50% carbon) success depends not only on the coating, but also on the microstructure of the metal. Two types of annealing are then used — normalizing and spheroidizing. The normalized structure is best for carbon steel wire if the part is to be trimmed and threaded after heading — because it then has better machining properties — but for some very severe heading jobs even on carbon steels the spheroidized type of structure is necessary. Alloy steels must be spheroidized or they are likely to be too hard for cold upsetting.



When you want guaranteed machining performance, exactness to size, straightness, definite tensile strength or any other combination of desired physical characteristics, put your problem up to Wyckoff metallurgical experts,—let them determine the exact chemical and physical values you require for economy and dependability. They offer you the advantages of many years of intensive specialization in meeting industry's most difficult steel problems.

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Recent Studies *on* Alloy Steels *and* Irons

Reviewed by

Francis B. Foley

Supt. of Research Dept.

The Midvale Company

(Who is not necessarily in agreement with all the statements made herein)

Photo by Margaret Bourke-White for Republic Steel Corp.

Grain Size Control Is the Latest Step Toward Perfection in the Making of High Grade Steel, Plain and Alloy

IF IT BE ASSUMED that the technical articles appearing in the publications of the American Society for Metals are representative of the interests of the membership at large, then grain size control in steel manufacture may be considered to have been of greatest importance to them during the past few years. The high point in this activity was reached in the symposium held by the Society during the 1934 Metal Congress. Likewise, H. W. McQuaid devoted his 1935 Campbell Memorial Lecture on "The Importance of Aluminum Additions in Modern Commercial Steels" to a detailed discussion of grain size control, its effects, and the theory underlying the action of aluminum. Others have entered the discussion of this development in the columns of METAL PROGRESS from time to time, and a large number of papers not devoted specifically to this phenomenon contain references to it, some of them important. As R. S. Archer, President, said in his address last year before the American Society of Mechanical Engineers, "Perhaps the most important metallurgical development of the post-War period is that of grain size control."

Aluminum as a Grain Refiner

In the 1934 symposium Samuel Epstein, J. H. Nead and T. S. Washburn gave a detailed account of the melting practice followed for high grade carbon steels, made in the basic openhearth, and the effect of aluminum and other elements in making steels of various grain characteristics. H. W. Graham also gave evidence that large grains improved the machining properties of bessemer screw stock. W. E. Sanders found coarse-grained steels were better for forging, producing dense forgings which were readily machined. In METAL PROG-

RESS, August 1934, a paper by R. L. Wilson summarized the effects of grain size on various properties of steel. Fine-grained steels, he points out, do not harden deeply, are not coarsened by a reasonable increase in the hardening temperature, produce a satisfactory product when casehardened by quenching directly from the carburizing box, and are tougher than coarse-grained steels. Coarse-grained steels, on the other hand, are deep hardening and therefore may be used for the manufacture of large pieces requiring heat treatment, and also have the advantage of greater machinability. (However, fine-grained steels, when annealed at a sufficiently high temperature, develop large grains and acquire the ease of machinability of coarse-grained steels.)

H. W. McQuaid's Campbell Memorial Lecture last year was a comprehensive account of the use of aluminum additions in the control of grain size. High aluminum additions caused small size of microscopical grain, a fine-grained fracture, a higher impact value, and a low order of hardness penetration. Aluminum is effective in controlling grain size even though the other elements normally present in the composition are higher than usual. The lecturer was not inclined to accept the common though unproven conception that the fine grain was the result of the formation of alumina which, existing as finely dispersed particles, supposedly acts as nuclei for the crystallization of many small grains, or as an actual barrier to the growth of grains.

This idea, he found, did not account for the fact that the aluminum has to be added within a very limited time before pouring, that the effect of the aluminum addition in large openhearth heats decreases rapidly toward the end of the pour, that fine-grained scrap has a tendency to produce fine-grained heats in electric furnace melting even with little or no aluminum addition, that boiling down eliminates this tendency, and that less aluminum is required in electric furnace melting under a reducing slag than is required in basic openhearth melting with its relatively more oxidizing slag. Likewise, a considerable excess of aluminum above that necessary to deoxidize the heat thoroughly is necessary to control grain growth, and finally the degree of deoxidation prior to adding aluminum is a governing factor only to the extent that it fixes the amount of aluminum required to furnish a surplus over that necessary for reaction with iron oxide, and it is this surplus aluminum in solution as metal which is effective in the control of grain size.

McQuaid suggested that it is the effect of aluminum, not alumina, on austenitic transformation and on the solubility of the carbides that accounts for its influence on grain size. According to this postulate, aluminum causes shallow hardening by decreasing the solubility of the carbides in austenite, and by raising the temperature and increasing the speed of austenitic transformation. When the critical temperature is raised the carbides tend to coalesce, and in this state of coalescence they are relatively less soluble in the austenite, already rendered less eager for the solution of carbides by the presence of aluminum. Thus undissolved carbide particles remain in the austenite to act as grain growth inhibitors. He also explained the inability to obtain intermediate grain sizes (which fact had already been stated by Epstein, Nead and Washburn in the symposium the year before) by the rapid action of aluminum in producing a fine grain. Once an effective amount of it has been added, the fine grain effect is rapidly attained by further slight additions.

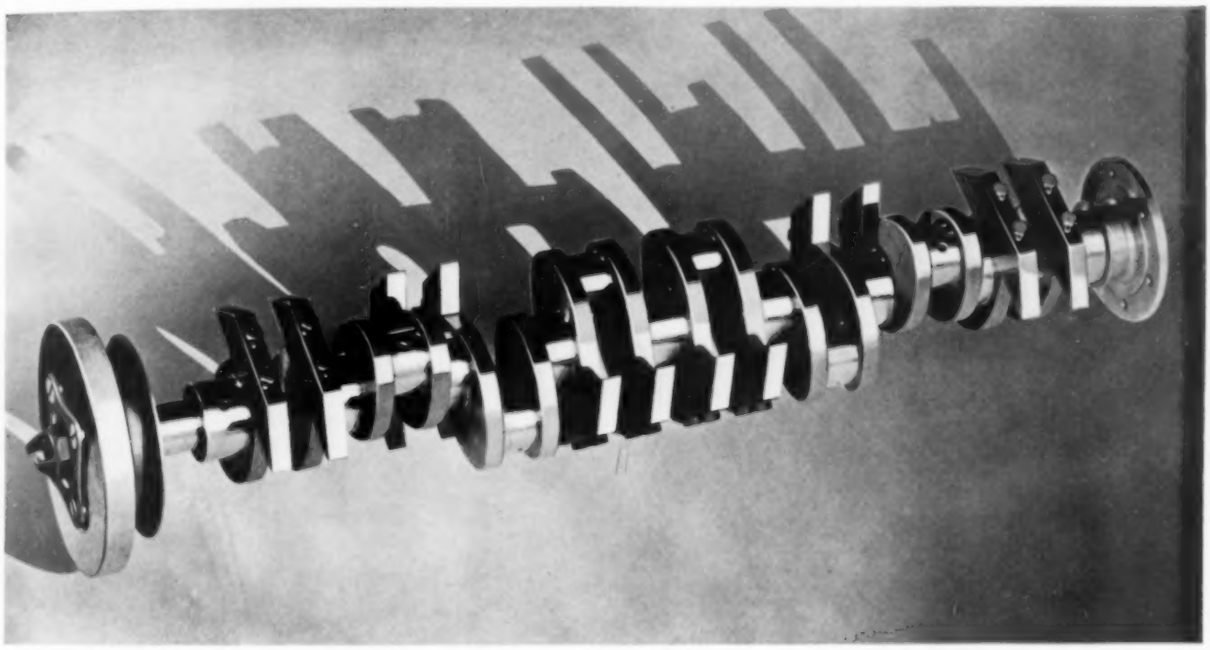
Coalescence of Carbides

The same author is presenting a further study of this question to the forthcoming convention. He studies the effect of varying aluminum on the structure of carbon steels that are substantially alike in added elements and alumina, and finds that aluminum in solution promotes a tendency toward wide ferrite envelopes around the pearlite grains in annealed steel, and promotes the accumulation of spheroidal carbides at the boundaries between pearlite grains and ferrite envelopes. These spheroids of carbide are "massive" as compared to the platelets of carbide in the pearlite, in the sense that the ratio of surface to volume is much less. Consequently it takes the spheroid a correspondingly longer time to go into solution (solution in this case being a matter of transferring matter across a limited boundary area) than it takes the pearlite to transform into austenite. Hence the carbide spheroids survive everything but a very long or a very high soak above the critical, and, persisting, act as obstructions to grain growth by boundary extension.

While on the subject of grain size control, which is essentially steel making, other data on the melting of steel should be noted. "Quality Control of Basic Electric Steel," an article by

R. P. Brown in the October 1935 issue of METAL PROGRESS, discusses melting practice at Timken Steel & Tube Co. In order to prevent porosity in the tops of ingots and cracks or flakes in the finished product, every precaution is taken to exclude hydrogen from the furnace during melting. This extends to the drying of raw materials used in making the steel and slag. Slags are analyzed chemically and examined under a petrographic microscope; all tapping slags, for instance, are analyzed for iron oxide as a guide to control grain size and abnormality.

A letter from Hans Diergarten in the June 1935 number of METAL PROGRESS concerns the relative merits of high speed steels melted in the electric arc and in the high frequency induction furnaces. German metallurgists find a difference in the fineness and distribution of carbides, favoring the metal from the induction furnaces. In other tests, including cutting tests, there was no difference found in experiments made at the Krupp works.



Crankshaft by Studebaker, Forged, Machined, Heat Treated, Balanced

Role of Titanium in Steels and Irons

George F. Comstock, in his article in METAL PROGRESS for January 1935 on "New Role of Titanium in Steels and Alloys," states that ferro-carbon-titanium is used, along with aluminum in the production of fine-grained steels, to improve cleanliness. (Although little has recently appeared bearing directly on the use of vanadium — an element long known to have a toughening effect — mention of it is made here and there in articles dealing with this general subject.) The affinity between titanium and carbon, responsible for the formation of a carbide insoluble in alpha or gamma iron, renders the carbon ineffectual as a hardening agent in steels containing much titanium; notably in the case of 4 to 6% chromium steel it prevents undesirable air hardening. In this connection a titanium content of four times the carbon is necessary. The use of titanium to prevent weld decay and intercrystalline attack of 18-8 has often been described.

In cast iron it refines the graphite flakes and appears to promote graphitization, as does silicon — a fact hard to explain in view of the readiness with which titanium combines with a little carbon in steel to form a stable carbide. Comstock also reports that the use of titanium in cast iron prevents hard spots and improves machinability.

Comstock's article deals with the use of titanium in both non-ferrous and ferrous alloys. He discusses its use in konel (nickel-cobalt alloys containing minor amounts of iron) and

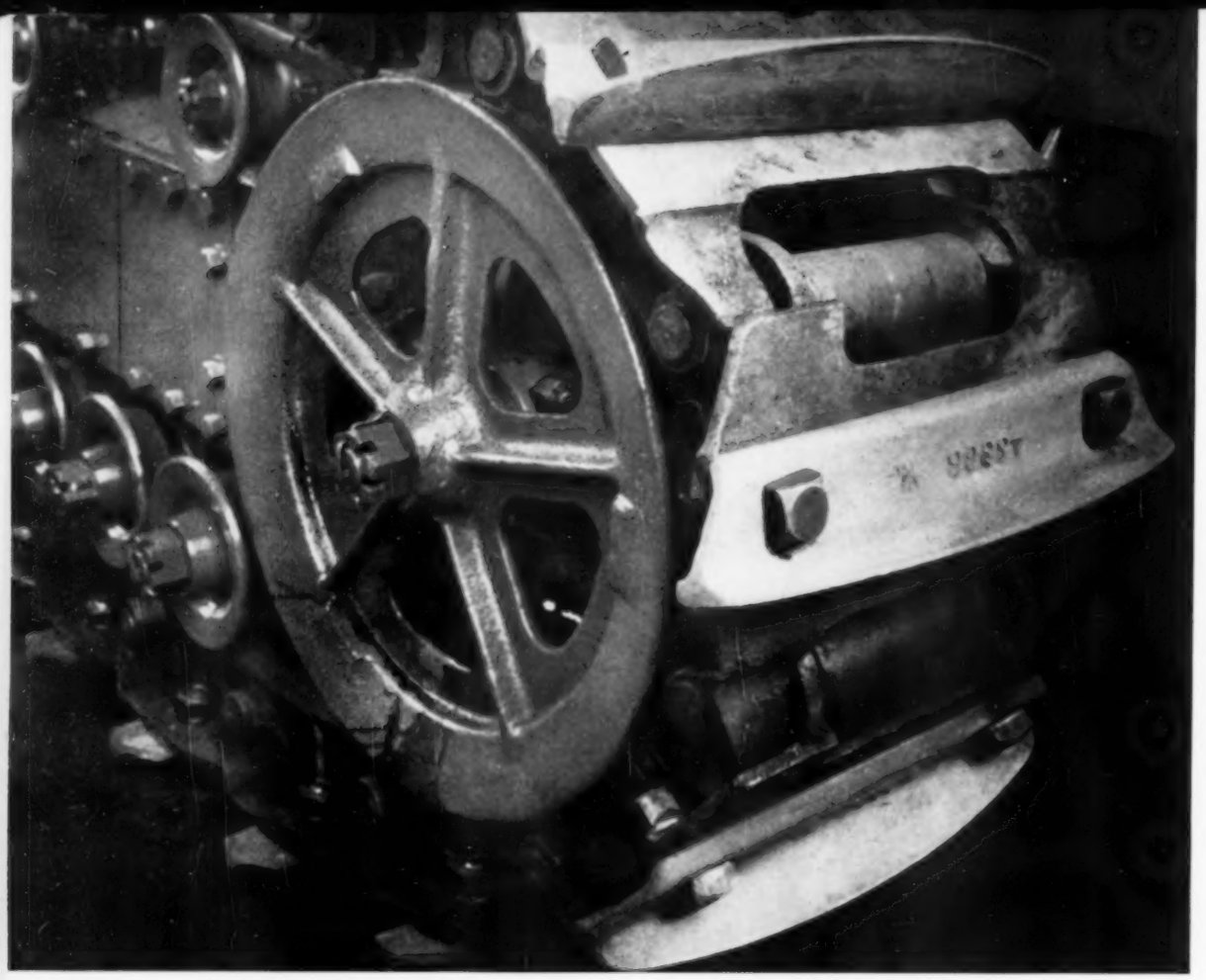


Photo by Henry M. Mayer at Cleveland Tractor Co.

Ready for Heavy Going — Thanks to Alloys and Heat Treatment

the remarkable age hardening effects of the compound Fe_3Ti in these alloys. In copper alloys, titanium is responsible for an interesting combination of strength and conductivity in age hardened alloys. When added to aluminum, titanium acts as a degasifier and forms a compound $TiAl_3$, nucleating crystallization and thus refining the grain.

It would appear that titanium has rather large and unsuspected potentialities as an alloying element, waiting only to be properly elucidated and commercialized.

Copper as an Alloying Element

A considerable amount of attention has been given in the publications of the American Society for Metals to the use of copper as an alloy in steel and cast iron. In METAL PROGRESS for April 1935 C. H. Lorig tells about the effect of copper on the constitution and structure of steel, on its physical properties, its corrosion resistance, its welding properties, its heat treatment and its hot working properties. With 1.9% copper the eutectoid forms at 1290° F. with a carbon content of 0.90%. A copper-rich solid solution, called epsilon, occurs as a network or as large particles during solidification and as tiny, sometimes sub-microscopic, particles upon precipitation from ferrite. Epsilon solid solution appears in the microstructure of high copper steels upon very slow cooling in annealing or after prolonged drawing; otherwise the structure of copper-bearing steels does not differ from that of ordinary carbon steels.

With less than 3% copper there is no effect in casehardening; physical properties generally are not affected with less than 0.5% copper. In amounts of 1% or 2% it increases tensile strength and yield point and lowers ductility (but at a less rapid rate than would carbon). With a 2% copper addition the Charpy impact value is increased. Resistance to atmospheric corrosion of mild steel is increased rapidly with copper additions up to 0.25% and more slowly with further additions.

According to Lorig low and medium copper steels are not hot-short if *(a)* a small amount of nickel be present, *(b)* if worked below 2000° F., or *(c)* if scaling be prevented. With several per cent of copper, steels may be distinctly hot-short. Weldability is not affected with copper up to 0.75%. Steels containing 0.60 to 4.0% copper, notably in the range 1.2 to 1.5%, may

be precipitation hardened by aging in the range 840 to 930° F. for from 3 to 20 hr.

The use of copper steels today is interesting in view of the fact, pointed out by E. E. Thum, in his note in the correspondence columns of METAL PROGRESS, July 1935, that copper was limited by specifications to 0.05% for many years because steels whose failures were unexplained otherwise were found to contain a small percentage of this element. This was done in spite of the presence of 0.20% of copper in the best Swedish wrought iron from which the leading domestic and foreign toolsteels were made, and regardless of the production of millions of tons of excellent bessemer steel with copper up to 0.50% from ore deposits near Cornwall, Pa.

The extent to which copper is being used by the Ford Motor Co. as an alloying element in steel and cast iron is attested by the article which appeared in the August issue by R. H. McCarroll and J. L. McCloud, giving the composition, melting, casting and treating of various parts entering into automobile construction. From 0.5 to 1.0% copper is used in cast iron according to type, and from 1.5 to 3.5% copper in steel castings. Copper in cast iron promotes soundness and controls depth of chill. The authors find that the fluidity of the metal is increased and shrinkage decreased by the addition of copper to their steel castings, and that copper also plays an important role in reducing the time of annealing. Copper-bearing cast iron is used for cylinder blocks, flywheels, pushrods and camshafts. Copper-bearing cast steels are used for clutch pedals, rear axle housings, brake drums, hub castings, crankshafts and for pistons for the Lincoln Zephyr. Valve seat inserts are made of a high carbon, high speed steel casting containing 1.5 to 2.0% copper.

Further use of copper in alloy sheet steel is described by Howard L. Miller in METAL PROGRESS for July 1935. This refers to a sheet steel of the following analysis: Manganese 0.50 to 1.00%, copper 0.50 to 1.50%, nickel 0.40 to 0.80%, molybdenum 0.20%, and carbon either 0.12% max., or 0.30% max. The greatly increased strength resulting from this combination of alloying elements enables a reduction of about 45% in the metal gage of automobile dump truck bodies and a reduction of four gages in tank trucks for hauling milk and three gages in those hauling gasoline. The author believes that with proper design a saving of 25% is possible in the weight of hopper cars.

Automotive and Machinery Steels

While the literature gives considerable emphasis to copper-bearing steels, advances were also being made in other types of low and medium alloy steels. This was set forth in an editorial article dealing with that subject in METAL PROGRESS for October 1934. Here low and medium alloy steels containing nickel, molybdenum, chromium, vanadium, silicon, manganese and copper are reviewed. In the July 1936 issue of the same magazine F. A. Wickerham discusses the use of a medium manganese steel (Mn 1.5 to 2.00%) for abrasion resistance, and last March A. B. Kinzel described the structure, treatment, properties and fabrication of structural and stainless steels containing silicon, manganese and chromium. The latter presents the facts systematically and refers them to metallurgical fundamentals.

Chromium in considerable amounts forms ferrite or delta iron, whereas manganese is an austenite-forming element. Moderate amounts

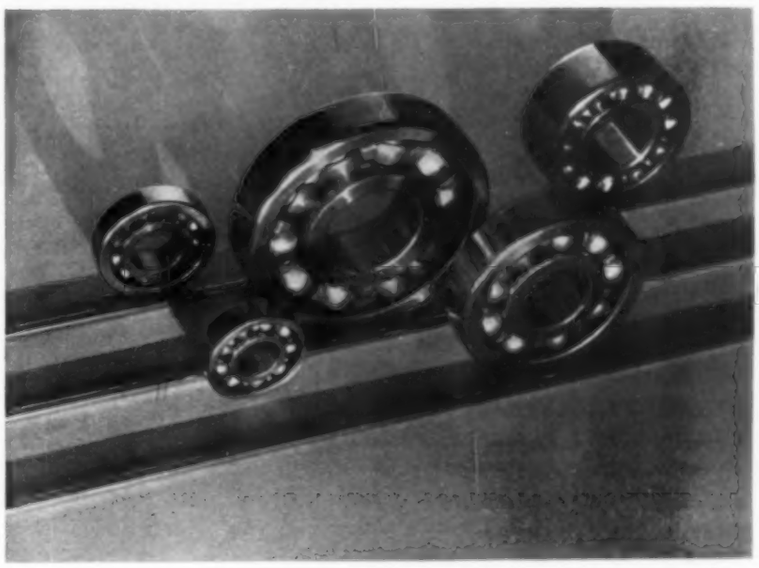


Photo by Dana B. Merrill for Fafnir Bearing Co.

And on the Other Hand, Precision Personified in Chromium Steel

of chromium influence heat treatment largely by slowing the transformation reaction rates, whereas manganese actually depresses the transformation temperature. Both elements form carbides readily, although chromium carbide is more stable; excess of either alloying element will dissolve in ferrite.

As examples of how these influences operate, Kinzel cited first a low carbon, 1% chromium steel — one with very desirable physical properties, for it is strong and yet reasonably ductile. If manganese goes beyond the usual 0.50%, the steel, while somewhat stronger, has a disproportionately lower ductility.

In the normalized medium manganese steels with 1.5% manganese and 0.30% carbon the pearlite and carbide distribution as well as the solid solution effect of the manganese, results in a relatively high tensile strength — for example 85,000 psi. The ductility remains sufficient for most engineering purposes. Increase in the carbon content very quickly changes the carbide distribution and lowers the ductility.

The addition of chromium improves this condition, apparently by decreasing both the carbon available for combination with the manganese and the tendency to micro-segregation, and by maintaining the proper distribution of pearlite and carbide after air cooling. This brought Kinzel to the question of how properly to proportion alloy in steel used in the as-rolled state, or how to arrive at a "balanced composition." He finds many desirable combinations. For steel sections up to 1¼ in., if the strength range is 70,000 to 95,000 psi. and carbon from 0.10 to 0.20%, the optimum ductility-strength relationship in the normalized state is obtained with 1.25% Mn and 0.5% Cr. This represents a balanced composition in the normalized but not in the as-rolled state. The addition of approximately 0.75% silicon tends to nullify the effect of variations in rolling practice and cooling, so that the above steel with this silicon content may be considered balanced in the as-rolled state as well as in the normalized state. A family of chromium-manganese-silicon steels has been promoted, following the principles as outlined (see S. M. Norwood, METAL PROGRESS, September 1934).

Standardized steels for ball bearings and roller bearings are noted by B. M. Suslov in a letter from U.S.S.R. appearing in the issue for December 1935. He gives four analyses for electric and openhearth steel. Carbon 0.95 to 1.10%, manganese 0.20 to 0.40%, silicon 0.15 to 0.35% and nickel 0.20% is base in all grades, the variations occurring in the chromium contents: *(a)* 0.45 to 0.75%, *(b)* 0.75 to 1.05%, *(c)* 1.05 to 1.40%, and *(d)* 1.30 to 1.65%. An intermediate grade contains carbon 0.30 to 0.42%, manganese 0.40 to 0.70%, chromium 0.80 to 1.20%, and is used for hollow rollers.

Other foreign developments are disclosed in an Italian letter from Federico Giolitti in METAL PROGRESS for February 1935. He states that increased speed and weight of trains has caused European railroads to resort to nickel-chromium and nickel-chromium-molybdenum steels, but there has been a recent tendency to abandon nickel-chromium steels for chrome-molybdenum steels for railroad crank axles.

Studies on Machine Parts

William H. Graves in his discussion of "What Steel Is Best for This or That Part" in last April's magazine discloses how the automotive industry dips into the pool of S.A.E. steels to satisfy the demands of the various makes. He finds that high alloy steels are not commonly used and predicts that even lower alloy steels and straight carbon steels will be the future trend.

A paper by O. W. McMullan on "Endurance of Casehardened Gears" read during the 1935 convention is to be followed this year by another on "Endurance of Gear Steels at 250° F." by A. L. Boegehold. McMullan resorted to the dynamometer for breakdown tests of rear axle drive gears and pinions. He found that S.A.E. 4615 steel quenched from the pot after carburizing made a good pinion and combined well with gears of Krupp analysis or S.A.E. 4820 double treated. He also observed that pinions were affected by moderate heat in service.

Boegehold's inability to correlate notched bar fatigue tests of rear axle gear steel with tests on rear axle sets led him to investigate the endurance of the steel in notched rotating beam specimens in oil at 250° F. (the estimated temperature attained by gears in service). He found that the number of cycles for failure at room temperature was 700 to 1500 per cent greater than in oil at 250° F. The gears tested were made of standard S.A.E. Ni-Cr and Ni-Cr-Mo analyses containing 0.15% carbon. Quenching from the carburizing box produced structures less resistant to fatigue than cooling in the box and subsequently reheating and quenching from above the critical. *(Continued on page 152)*

Toolsteel

New and Old

Studied Intently

Review of Literature

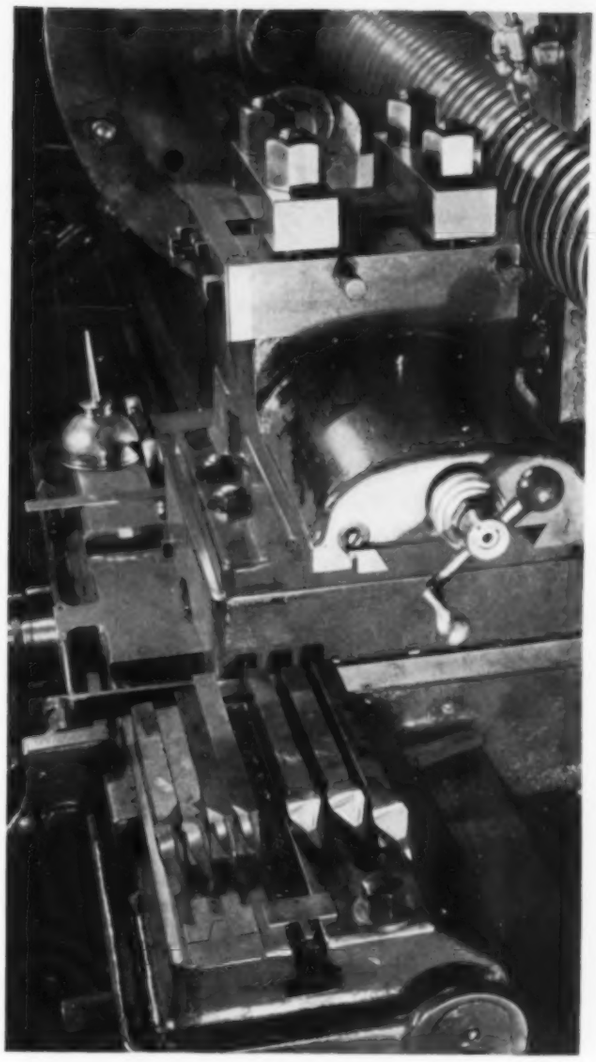
by James P. Gill

Metallurgist

Vanadium-Alloys Steel Co.

Latrobe, Pa.

(*who is not necessarily in agreement with all the statements made herein*)



Turning Accurate Threads on a Large Drive-Screw. Photo by W. H. Hoedt for Wm. Sellers & Co., Inc.

NUMEROUS papers, discussions, letters, Chapter reports of lectures, recommended practices, and several books form the literature originating from American Society for Metals which indicates the recent developments in the field of toolsteels. To summarize these data they have been grouped into several subdivisions.

Recently Developed Compositions

Our literature is usually slow in recording new compositions of toolsteels, since many companies are continuously testing new materials and they are reticent to have the compositions appear in print until they are reasonably satisfied that the materials are commercially practical. In most instances new compositions are developed for specific and restricted applications and may not be of general interest; the development of a steel of general application is therefore of widespread importance and such is reflected in the literature. Consequently a number of articles appeared during the last few years on the development of the molybdenum-tungsten type of high speed steel, a typical composition of which would be: Carbon 0.76%, tungsten 1.60%, molybdenum 7.90%, chromium 3.85% and vanadium 1.10%.

Frank Garratt in an article appearing in METAL PROGRESS, June 1935, has given an excellent description of this steel, including methods of fabrication and heat treatment, as well as its physical characteristics. It was developed independently by both a steel maker and a twist drill manufacturer; the molybdenum is seen to be about half the amount of tungsten (by weight) replaced in an 18-4-1, and about five times the amount of tungsten remaining. Some of the lectures given before the different Chap-

ters of the Society last year indicate that other compositions of molybdenum high speed steels may soon be offered commercially, but data regarding them have not yet appeared in print.

Recommended practices for heat treatment are only made after an alloy composition has become established, which is usually from two to five years after its commercial introduction. The 1936 Metals Handbook has recommended practices for the heat treatment of several types of steels not mentioned in previous handbooks. One of these steels, which contains about 0.30% carbon, about 0.80% silicon, 5.0% chromium and 1.0% molybdenum, with or without a small amount of tungsten, is given as a composition for dies for die casting aluminum, magnesium and copper base alloys.

One of the outstanding developments during recent years has been the methods for controlling grain size and case depth of carbon toolsteels. Thus the oldest type of toolsteel, while not changed in composition, is being produced with a remarkable degree of uniformity.

Testing Methods

The testing of toolsteels, whether for purpose of evaluation or for appraisal of quality, has always presented difficult problems. The 1936 Handbook will contain an article on this subject which is the work of the Subcommittee on Toolsteels. This will describe clearly and briefly substantially all of the different types of testing that may be applied to toolsteels, pointing out their advantages and disadvantages. It is the result of several years' work by the committee and a most valuable addition to the literature on the subject.

G. V. Luerssen and O. V. Greene have published further information in a paper for the 1935 convention interpreting the torsion impact test as applied to carbon toolsteels, and have shown that the three stages in the characteristic torsion vs. impact curve for a quenched and tempered carbon toolsteel coincide with the three generally recognized structural changes encountered in the full tempering range. The work of Luerssen and Greene on torsion impact and that of J. V. Emmons on the static torsion test (*Transactions*, February 1932) have been most valuable contributions toward crystallizing the lay opinion and in differentiating strength, toughness and plasticity in toolsteels. Robert S. Rose in a letter to METAL PROGRESS, July issue, has further clarified the relationship of these properties, especially as related to speed of loading.

B. F. Shepherd, Past-President, has elaborated his method of test procedure and classification of the hardenability and susceptibility to grain growth. This is primarily for carbon toolsteels, and is likely to be generally accepted as a standard. Shepherd's work, systematically classifying case depth and grain size (which he terms the "P-F Characteristics") will permit a discussion of these factors in a common language readily understandable.

Physical Characteristics of Specific Materials

E. C. Bain, President-Elect, in the seventh Campbell Memorial Lecture (1932) discussed the factors affecting the inherent hardenability of steel. Since the presentation of this notable lecture many investigators have published considerable supplementary information, defining these factors in specific reference to carbon toolsteels. The above-mentioned work of Shepherd was of fundamental importance in that it showed the great differences and many variations in hardening characteristics of steels of the same chemical composition, as judged by routine analysis.

T. G. Digges and Louis Jordan, in a contribution to the 1935 Metal Congress, compared two commercial 1.0% carbon toolsteels which had widely different P-F characteristics. They found that for quenching temperatures below that at which all the carbon was completely dissolved in the austenite, both the austenitic grain size and the critical cooling rates were influenced by the initial structure, but that above this temperature each steel approached a grain size and a critical cooling rate that was characteristic of the steel, regardless of its initial structure. Reinhold Schempp, commenting on the work of Digges and Jordan, summed up the effect of prior heating on the same carbon toolsteel when treated to have either a coarse or a fine grain. If this steel is cooled rapidly to a fine grain and then subsequently heated to temperatures above the critical, it will coarsen more rapidly than another sample that has previously been slowly cooled to a coarse grain. At low temperatures Schempp finds that the coarse-grained material is deeper hardening but that when the quenching temperature is reached where a fine grain will coarsen, the values are practically the same, and that at higher temper-

atures the fine-grained material becomes the deeper hardening. In this connection Digges and Jordan determined the critical cooling rates on their two steels from three different initial structures but made no comment as to what effect rapidity in heating for quenching might have on the case depth.

Schempp's later article in August 1936 METAL PROGRESS entitled "Quality Toolsteel" outlined methods of inspection, testing and applications, and offered an additional explanation as to the factors influencing hardenability. He mentioned this interesting feature about prior structure: Under similar hardening conditions, where the quenching temperature is no higher than 75° above Ac_1, hyper-eutectoid carbon toolsteels will harden deeper if they have a prior spheroidized structure than though they had a sorbitic or partially lamellar pearlitic structure. He explained this phenomenon on the basis that the spheroidized structure produces austenite very close to the eutectoid composition, whereas the austenite from sorbite is hyper-eutectoid. He did not state that some investigators had found this phenomenon to be related to the characteristics of the particular heat or melt.

J. R. Vilella and E. C. Bain have given in the last issue of METAL PROGRESS a comprehensive discussion of the methods of revealing the austenitic grain size. They show that for practical purposes the macro grain size of carbon toolsteel as indicated by the fracture is comparable to the austenitic grain size as indicated by the microscope.

Two excellent papers for the 1934 and 1936 conventions by W. H. Wills on "The Physical Properties of High Carbon, High Chromium Toolsteels" indicate that the carbon content as well as small amounts of other elements have a pronounced effect upon the impact values of steels of this type. In comparing two tempered steels, one containing 2.4% carbon and 11.5% chromium and the other containing 2.1% carbon, 12.0% chromium and 1.0% vanadium, he found that at practically the same Rockwell hardness the latter had two to three times higher impact value. (While it is true that vanadium may account for part of this effect, allowance should be made for the difference of 0.30% carbon.) Wills also studied a third type of high carbon, high chromium steel which contained 1.55% carbon, 12.0% chromium, 0.25% vanadium and 0.80% molybdenum, and found that this third type showed impact values approximately three times that of the steel containing 2.1% carbon, 12.0% chromium and 1.0% vanadium, when using the same tempering temperature and with roughly comparable hardness. He likewise gave interesting information showing the effect of varying the quenching temperature on specimens of different sizes.

Making a Torsion Test on Hardened Tool Steel
Courtesy Cleveland Twist Drill Co.

Heat Treatment

The Subcommittee on Toolsteel of the Metals Handbook Committee is composed of 16 members, eight of whom represent manufacturers and the other eight large consumers of toolsteels. This committee has revised all of the recommended practices on the heat treatment of toolsteels which appear in the old handbook. Many changes have been made in the practices so that the 1936 edition will contain notes on

what is considered the most modern in heat treatment of toolsteels. Undoubtedly these recommendations will form the basis for much careful work in the future.

The effect of furnace atmospheres on the structure of steel has been the subject arousing the greatest amount of discussion in the field of heat treatment. It will be discussed generally by E. O. Mattocks in another section of this issue. Here we will concern ourselves only with the problem of high speed steel.

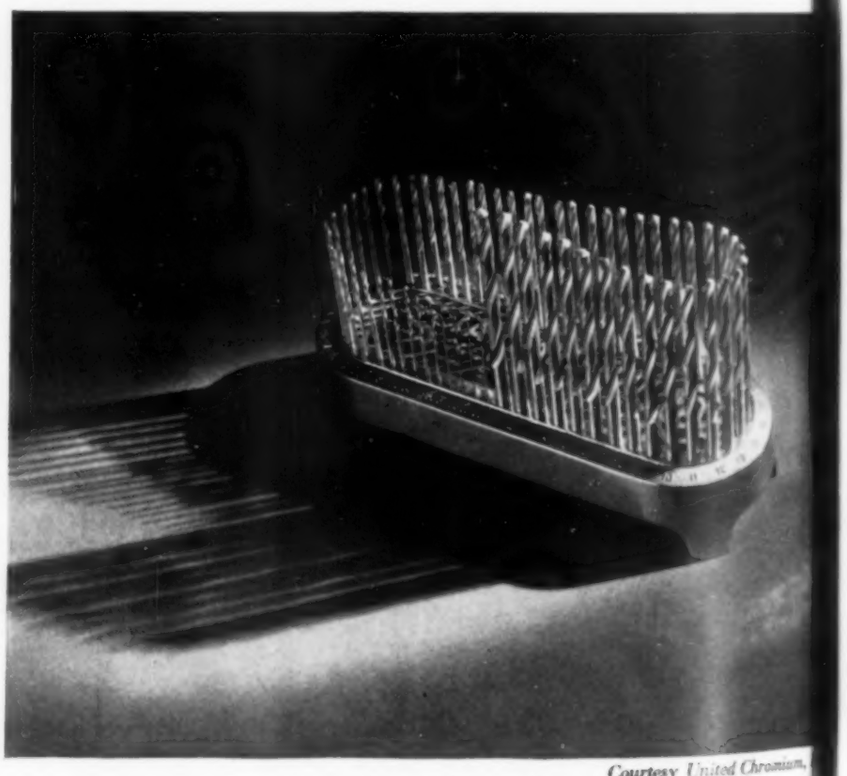
Sam Tour first published a paper on this subject in 1930; a later paper in *Transactions*, March 1933, gave the results of his studies on the effect of gas atmospheres on a standard 18-4-1 high speed steel. Tour's general conclusion was that the grain size in high speed steel is affected by the gas which surrounds the steel during heating for hardening. In his experiments the grain was coarsened when the atmosphere was "oxidizing" (containing free oxygen as determined in an Orsat test set); if the atmosphere was "reducing" in the sense of containing considerable CO, the microstructure and fracture remained fine grained. His supposed causes for these facts were contested by E. E. Thum who advanced the hypothesis that grain growth was in proportion to the inhomogeneities in composition existing in the toolsteel bar before heat treatment, and these were increased by oxidizing gases (which formed more of the delta solid solution) and decreased by carburizing gases (which converted some of the free iron to carbide).

In a series of lectures on toolsteel presented before the 1934 annual convention, James P. Gill also took exception to Tour's conclusions and stated that it appeared that the atmosphere in itself had no influence on either the rate of growth of the austenitic grain or on the fusion point of the segregate so long as it did not change the composition of the steel by carburizing or decarburizing, and that the gas surrounding the steel at the time of heating for hardening indirectly affected the size of the austenitic grain only as it affected the true temperature of the specimen.

In this same connection Arthur Phillips and M. J. Weldon, in studying the effect of furnace atmosphere on grain size of a molybdenum high speed steel (*Transactions*, December 1935) showed substantially the same effect on this type of steel as Tour did on an 18-4-1 high speed steel. In a discussion of this paper, Gill pointed out that the investigators had used sheet stock only $\frac{1}{16}$ in. in thickness, the surface of which had not been removed; therefore, because of the thinness of the material with an unknown surface condition, the results could not be accepted with any degree of confidence. Messrs. Weldon and Phillips answered that the results had been checked on ground samples.

Thus it does not appear that sufficient investigations have yet been made as to the effect of gas atmospheres on the structure of high speed steel to satisfy the opposing opinions which exist on this important phenomenon.

An interesting practical experiment was made by Owen W. Ellis on the tempering of high speed steel (METAL PROGRESS, October 1935). Eight different heat treaters hardened and tempered portions of an 18-4-1 high speed steel bar under eight different sets of shop conditions. They were asked merely to use a specified



Courtesy United Chromium, Inc.

A Set of Beauties

quenching temperature and tempering temperature. The results indicated that there was no material difference in the hardness of the specimens whether they were tempered 30 min., 60 min. or 120 min.

Double tempering is supposed by some to improve tools. Tests on an 18-4-1 high speed steel were made by Russian investigators by double tempering at 1050° F., holding for 90 min. each time and subsequently cooling in air. The steel had an initial hardness of Rockwell C-64 which increased to C-67 after a single tempering, and only to C-68 after re-tempering to the same temperature. However, the Russians claimed that re-tempered tools machined approximately 12 pieces versus 8 pieces by a tool that had been given a single tempering.

Different authorities in this country have recommended such double tempering, yet the merit of such procedure has been open to question. It seems that if the original time at the tempering temperature was insufficient to transform the austenite completely, a second tempering may be beneficial. If, however, the material had been held a sufficient length of time when *originally* tempered, it is difficult to offer a logical explanation as to why a second tempering should measurably change its hardness or cutting ability. Other metallurgists have advocated re-tempering after the tool was finish ground. Such a suggestion may have merit on the basis that final tempering may remove grinding stresses which might contribute toward chipping of the cutting edge. Along this line of thought it might be reasoned that double tempering will relieve hardening stresses to a better degree than single tempering, thereby bringing about increased toughness.

Tool Design

A paper by O. W. Boston and W. W. Gilbert in *Transactions*, September 1935, and another by the same authors and C. E. Kraus in the March 1936 issue are valuable contributions on the design and form of cutting tools. For single point cutting tools they showed that changing the nose radius, the side cutting angle and the side rake angle would vary the cutting speed greatly without changing the temperature of the nose of the tool. They also found that the surface color of the heated chips was not a direct indication of the tool temperature, and that different cutting fluids produced a different relationship between cutting speed and tool life. They showed that for a given area of cut, other factors being constant, the results obtained with a shallow, thick cut differed from those of a deep, thin cut, and that oils did not have the same effect when the dimensions of the cut were varied from the deep, thin type to the shallow, thick type.

Foreign Practice

During recent years foreign practice has apparently borrowed considerably more from American practice than vice versa. Two letters from foreign correspondents have recently appeared in METAL PROGRESS which give some indication as to the type of steels being used.

Albert Portevin reports from France last September that their carbon toolsteels are made with a variable carbon content and with variable hardenability characteristics. This would indicate they were similar to the American types! He reports that most of their high speed steel is of the 18-4-1 type and that they use a considerable quantity having a lower tungsten content than 18%, but that a steel containing 22% tungsten and 4% chromium is widely used for milling cutters. The compositions reported for other types of tool and die steels cover such a wide range that it is impossible to make a comparison with American types.

B. M. Suslov reports (January 1935 METAL PROGRESS) that carbon toolsteels in the Soviet Union are quite comparable in composition with those in this country. High speed steels in use over there seem to be chiefly of the 18% tungsten, 4% chromium, 1% vanadium type, or more preferably of the 12% tungsten, 4% chromium, 2% vanadium type. Suslov indicates the use of one cobalt high speed which would be similar to an 18-4-1 type plus about 5% cobalt. He also states that they have 21 standard grades of alloy toolsteels, but does not give analyses.

Books

Two books pertaining to toolsteel and its treatment have recently been published by the Society. One of the books constitutes the series of lectures on toolsteels given by J. P. Gill at the New York convention, 1934, and the other the lectures on heat treatment given by Marcus A. Grossmann at the Chicago convention, 1935. Both books are concisely written and should be valuable to shopmen and engineers who lack metallurgical training.

"63" STOODITE

● The extreme hardness of Stoodite "63" (it tests from 63 to 66 Rockwell C) combined with its ability to retain hardness at red heat make it invaluable for tippng tools used for cutting such materials as 12%-14% manganese steel, chilled cast iron and heat-treated alloy steels.

"54" STOODITE

● Stoodite "54" is not so hard as Stoodite "63" nor so tough as Stoodite "45," but it combines, to a great extent, both of these qualities. Because of its hardness and toughness, it is best suited for general shop usage. Like Stoodite "63," this metal has the ability to retain hardness at red heat. Applied to S.A.E. 1045 steel, it can be used in lathes, shapers and boring mills for cutting plain and alloy steels, as well as cast iron.

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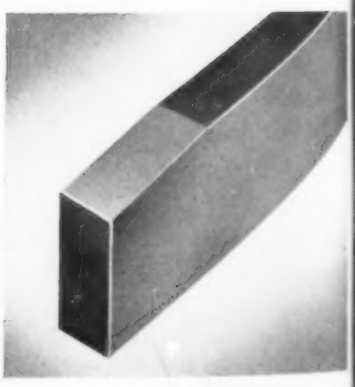

1 Making a lathe tool with Stoodite "54" or Stoodite "63" is simple. Select a piece of S.A.E. 1045 steel of a suitable size and grind the end that is to be hard-surfaced as in 1.

2 Adjust the torch flame until it is definitely carbonizing. Heat the end of the blank until it begins to sweat; then apply the Stoodite "54" or Stoodite "63". 2 illustrates the completed application.

3 Rough grind the tool into approximately the desired shape on a coarse wheel and finish it on a finer wheel. 3 illustrates a finished turning tool.

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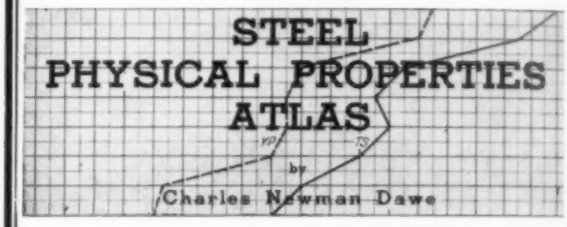

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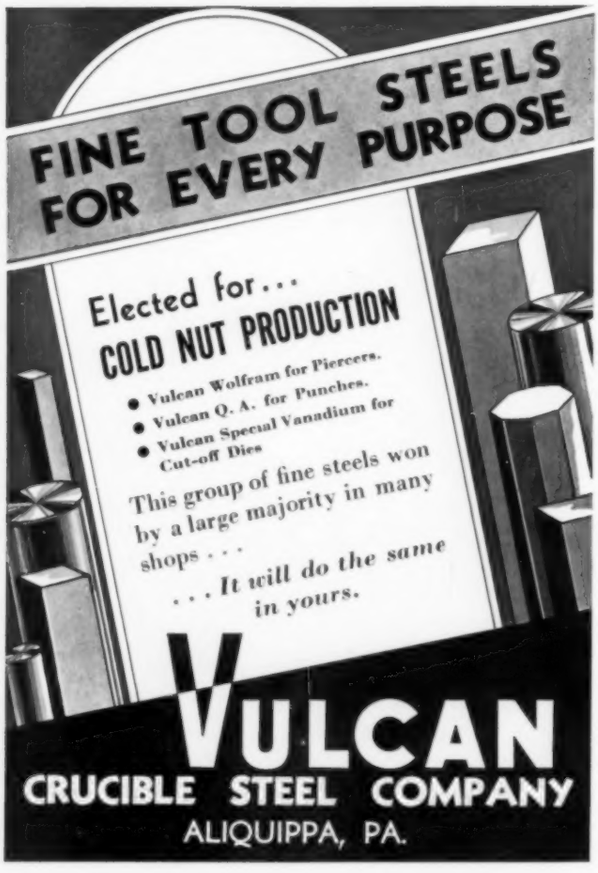
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Alloy Steels

(From page 136) Boegehold suggests hydrogen embrittlement, arising from organic acids present in the oil, as the cause of the low durability at 250° F.

Electrical Sheet

A paper on the manufacture and properties of electrical sheet (3% silicon) read at the 1934 convention by N. P. Goss was followed by a paper on the same subject by Richard M. Bozorth and another by T. D. Yensen and N. A. Ziegler presented before the Society at its 1935 convention. Goss produced a fine-grained silicon strip steel having magnetic and electrical properties far in excess of those obtained by the regular hot rolling method and approaching those of single crystals. His best results were obtained when hot-rolled strip was annealed and then cold rolled to an intermediate gage, heat treated, cold rolled to final gage, and again heat treated at around 2000° F. Goss said his magnetic properties were not to be accounted for by preferred orientation, since none appeared under X-ray examinations. In the discussion this reputed random orientation was questioned by Bozorth who studied a sample of material furnished by Goss.

Yensen and Ziegler studied the effect of carbon, oxygen and grain size on the magnetic properties of iron-silicon alloys with silicon ranging from 2.5 up to about 6% and carbon from little more than a trace up to 0.30%. Oxygen had no appreciable effect on the magnetic properties of alloys containing 3% or more of silicon when tested at low density, but did affect the permeability at high density. Carbon has a large effect, but when present in amounts of less than 0.01% this is not as great as had previously been indicated. With carbon from about 0.005 to 0.05% and silicon 3%, carbon occurred as cementite, Fe_3C, but was partly precipitated as graphite when silicon was as high as 4 to 6%. Pearlite remained as such after short annealings at 2010 to 2090° F. but the carbide may change to graphite after prolonged annealing at lower temperatures. Magnetic properties were found to depend on the form of the carbon, whether graphitic or as carbide, either plates in pearlite or separate particles. The effect of grain size, in turn, depends on the silicon and carbon.

Hardness Tests Equipment *and* Operation

By Joseph G. Gagnon

Chief Metallurgist

Hudson Motor Car Co., Detroit

Photo by Harold H. Costain for Wilson Mechanical Instrument Co.

Rockwell Hardness Tester

AN ARTICLE on "Routine Inspection of Automotive Parts" in the last issue of METAL PROGRESS attempted to bring out methods which, in my estimation, are nearest to checking service requirements. Owing to space limitations the subject of physical testing instruments and tools was passed over with slight mention. Since great dependence is placed on routine hardness tests, it is now not amiss to revert to this matter, especially in the section of this special issue devoted to instruments for testing and control.

Before going further, it should be pointed out that the metallurgist and engineer engaged in controlling mass production regard their testing equipment in an entirely different light than the research man. Testing instruments, to the former, are tools that will indicate the acceptability of the part for the next operation or assembly. They therefore choose equipment after studying the size, shape and surface condition of the part and its various steps of manufacture, both past and yet to come. While hardness testers are the main reliance, it should be remembered that hardness is merely a crude approximation of the true physical properties of the part; the latter have been determined in other ways and at other times, and a manufacturing routine set up that is expected to meet the requirements. The routine testing is primarily to prove that essential steps in this manufacturing routine have not been slighted.

The File

Let us start with the oldest, cheapest and commonest of all — the file — a bar of hardened steel of various shapes into which have been cut numerous teeth. Spacings and contours vary with the class of file and it is graded accordingly. The "mill files" are finely cut and generally used for routine inspection of automotive parts. (See the article on File Hardness Test in Metals Handbook.)

It is not only necessary that the file be passed slowly over the object to be tested, but

the pressure, speed and angle of movement, and the condition of the file are all important factors if the proper results are to be obtained on steel of constant composition and heat treatment. A good file in the hands of an experienced inspector will give reliable and accurate results. In addition to being a non-destructive test, it is the only rapid and practical tool which can cover the entire surface of the finished part. I am told that a large manufacturer of gears uses nothing but files for gear inspection, in which they are graded into four "touches." Needless to say, his inspectors have been taught the proper use of the file, and frequently check its condition on a standard hardness block.

Another point in favor of the file is that even the furnace operator can use it constantly to test his work, thus enabling him to detect improperly hardened parts and make the necessary corrections.

The file has its limitations in the inspection field and principally applies to surfaces that are file-hard and harder. The above advantages should be considered only if the part in question adapts itself to that type of test. This tool is sometimes used in conjunction with other instruments so as to check various structures (as would be the case of a carburized part) where file hardness would not confuse a desirable austenitic structure with an undesirable troostitic spot. Harry W. McQuaid ⬢ has discussed this point in METAL PROGRESS, March, 1935.

The Scleroscope

The principle employed in the scleroscope is, as is well known, the drop and rebound of a diamond tipped hammer, dropping freely in a glass tube from a fixed height. The resulting rebound is caught by eye against a graduated scale, or registered on a dial. The scale is determined by dividing the rebound from a quenched test block of high carbon steel into 100 equal parts.

Since the hammer has a very small mass, the mark left on the surface by the spherical tip is very small, and harmless except to polished surfaces. It is obvious, also, that the hardness measured is the hardness of a very thin surface layer of the metal. Therefore, we use the instrument only when hardness is high and when *surface* hardness is in question. Another place where the scleroscope is a rapid instrument is for the sorting of mixed material of wide hardness variations.

The following precautions for its use are taken from advance sheets of the 1936 edition ⬢ Metals Handbook.

1. Do not allow the hammer to strike more than once on the same spot or too near it.
2. Mount specimens as solidly as possible.
3. Testing of small pieces is best conducted in a bench vise with scleroscope mounted on a swing arm. Use soft steel, copper or lead sleeves on the vise jaws.
4. Average readings should be taken in all cases where local characteristics are not being studied.
5. The operating mechanism should be properly lubricated with a light, high grade oil. On the bulb machine no oil should be permitted to enter the glass tube. With the dial machine oil must be kept away from the clutch mechanism.
6. The hammer should fit into the tube properly.
7. Keep the instrument clean at all times.

Scleroscope in Use at Pratt & Whitney Aircraft Plant for Quick, Portable and Non-Destructive Tests on Motor Parts. Courtesy Shore Instrument & Mfg. Co.

Low readings may be due — 1. To friction from dirt in the glass or on the hammer.

2. To clogged vent holes in the bottom cap of the barrel which interfere with the escape of air under the falling hammer.

3. To a loose diamond. (This may be determined under a magnifying glass by tapping the stone lightly.)

4. To being out of plumb.

5. To striking a glancing blow when impacted surface is not level.

High reading may be caused — 1. Under exceptional conditions by wear on the diamond point. Hammers that read too high should be redressed and restandardized. This can be determined by use of standard blocks.

2. When the valve ball becomes clogged with dust so that it cannot set properly some air will enter the glass tube chamber, which causes the hammer to drop with a greater velocity, with the result that abnormally high readings will be obtained.

Brinell Hardness Test

The Brinell hardness test measures resistance to indentation.

Logically it should have been placed first in this discussion, for it was the first test used extensively by the metallurgist, and has been so widely applied that "resistance to indentation" has been accepted as the technical meaning of the word "hardness." The Brinell machine was first exhibited at the 1900 Paris Exhibition by the Fagersta Co. of Sweden, and was characterized by Henry Marion Howe as the most interesting metallurgical exhibit at that exhibition. However, its importance was not equally apparent to other Americans, for it was adopted slowly and we find one of the earliest conferences of the A.S.S.T. (Pittsburgh, 1923) concerning itself with the measurement of hardness in routine inspection.

The Brinell machine is essentially a small and accurate hydraulic press which can apply a load varying at will from 500 to 3000 kg. on a hardened steel ball, thus pressing it into the smoothed surface to be tested. The diameter of the resulting indentation, properly measured with a low-power microscope, is converted to "Brinell hardness number" by reference to tables, previously worked out by a formula. Loading, diameter of ball, and diameter of impression enter this formula in such a way that the hardness numeral measures the relation between load and volume of metal displaced. The smaller the indentation, other conditions being equal, the higher the Brinell hardness.

The Brinell machine is the nearest to a nondestructive instrument which will indicate the tensile properties of the metal tested. This approximate relationship, however, extends only up to some 477 Brinell hardness numbers. Whenever size of the part, shape or surface conditions warrant, it will be recommended for testing annealed or heat treated forgings, castings, bolts, shafts, and any parts not too hard on which the ball impression will not impair the serviceability.

This test, properly applied, gives the metallurgist a greater degree of security in the confidence that the part was properly processed. However, it is not able to pick out an overheated forging nor one lacking refinement.

Due to the frequent necessity of smoothing the part to be tested and the trouble of reading the indentation, the inspection costs are higher with the standard Brinell machine than with the newer types of indentation hardness testers which do not require surface preparation and are self-reading. These latter may have their merits, but the writer believes that accuracy is severely imperiled whenever surface conditions are not as good as they should be.

General precautions in this test will be discussed below. Some special precautions are advisable: The Brinell test should not be used on samples of soft steel which are less than about ½ in. thick or on samples so small as to allow flow of metal at the edges as a result of the ball impression. As there may be some sticking of the mechanism in the hydraulic, hand-operated machine, the pumping should be done more slowly as the maximum load of 3000 kg. is approached; otherwise the pressure may go over the load.

Rockwell Hardness Test

The Rockwell tester was introduced about 15 years ago and soon became popular. It is essentially a penetration instrument wherein the correct load is automatically applied at a standardized rate and the hardness read from a dial registering the *depth* reached by the penetrator (steel ball or diamond cone). Several scales are in use, referring to major load and type of penetrator. Due to its flexibility, this machine can be used for the testing of materials of various hardnesses and heat treatments. Depend-

ing on the material to be tested, we have the use of penetrator balls ranging from ½ to $\frac{1}{8}$ in. and in addition the conical-shaped diamond "brale." With these, loads of 60, 100 or 150 kg. can be applied.

When specifying this type of test, physical structure and properties are again our guide in selecting the load and penetrator. It is most useful for the testing of parts in the semi-finished stage or on finished parts where a slight disfiguring of the surface has no bearing on its service requirements.

As flexible as this machine is, it has its limitations. Although the values it gives are more nearly related to the Brinell hardness than the scleroscope, its results cannot always be accurately correlated with Brinell — accuracy, in this case, being dependent on chemistry, method of manufacture and heat treatment of the metal under test. However, suitable comparative tables can be worked out by the metallurgical department for specific types of material or parts, as will be demonstrated later.

Let me point out a few of the preliminary requirements for proper procedure in the satisfactory execution of a test — a Rockwell hardness test, for instance. First, the machine must be properly calibrated and it must be level and free from vibration. Second, the part being tested should be free from scratches and surface decarburization and be square under load. Third, the speed of making the test must be within the standards set up by the manufacturer of the machine.

Accurate set-up is the thing most often neglected by operators. To indicate its importance the following experiment was made: A test block of C-62 to C-63 hardness, on which a 2° taper had been ground, gave the following results: Flat surface, C-62 to C-62.5; taper ground surface, C-61 to C-61.5. This may not appear excessive, but the maximum difference of 1½ points due to a very slight angularity might cause considerable disturbance to someone's peace of mind.

Other precautions are listed in the Metals Handbook, and are well worth studying. Again it may be emphasized that test results are comparable only to that degree of accuracy to which they are made.

Choice of Equipment

There is no such thing as a "best hardness tester"; each of the three discussed above has its place in the field and there are others available and favored by competent critics. The best for a given set of conditions is the one that will give the most accurate results under proper procedure. Specifying the proper test for a given

Testing Hardness of Forged Lever With Brinell Machine

Photo by Van Fisher at Steel Improvement & Forge Co.

Variations in Hardness of S.A.E. Steels Tested With Different Machines

	4620	4620	1040	1040	1035	1035	5145	4640	4130
Material	Bar Stock	Bar Stock	Forging	Forging	Forging	Forging	Bar Stock	Forging	Forging
Quench	1520°F.	1520°F.	1520°F.	1520°F.	1540°F	1540°F.	1500°F.	1500°F.	1520°F.
Medium	Oil	Oil	Water 160°F.	Water 90 to 110°F.	Water 160°F.	Water 90 to 110°F	Oil	Oil	Water
After Tempering; Hardness Along Diameter of Circular End									
Brinell	241	235	217	269	241	285	277	269	269
Rockwell C	22 to 25	20 to 25	19 to 21	29 to 31	24 to 27	30 to 32	29 to 30	28 to 29	27 to 28
Rockwell B	100 to 101	99 to 104	95 to 103	107 to 109	105 to 108	106 to 108	106 to 107	104 to 106	104 to 105
Scleroscope	45 to 47	46 to 48	44 to 46	45 to 48	52 to 53	52 to 53	53 to 54	51 to 53	50 to 52
After Cutting Test Specimen in Two; Hardness Across Diameter of Cross Section									
Brinell	235	229	212	223	197	241	269	269	269
Rockwell C	18 to 22	18 to 23	14 to 24	17 to 27	12 to 20	20 to 27	27 to 29	23 to 27	25 to 27
Rockwell B	97 to 102	97 to 102	93 to 101	96 to 103	92 to 102	100 to 106	104 to 105	103 to 104	103 to 105
Scleroscope	46 to 46	42 to 44	38 to 42	44 to 46	36 to 40	46 to 48	48 to 50	48 to 50	49 to 51

part often is a rather difficult problem, as I will try to illustrate:

Take a chilled cast iron valve-tappet. The object of the test is to assure ourselves that, the proper specifications having been followed, the product is of the proper hardness and has the depth of chill necessary for its proper performance in service.

Properly tested with a scleroscope, the rebound would indicate a very hard surface, say 85 to 90 units. Using a file, the same conclusion would be reached as regards surface hardness. Neither of these two methods would indicate depth of chill, which is also a major requirement for this part.

So we might specify the Rockwell machine, which might show a hardness of C-53 to C-54. True, this machine, due to its applied load of some 330 lb., gives us a better indication of chill-depth than the file or scleroscope, but it is still not an accurate service evaluation because this same part, manufactured from an alloy steel, properly carburized and hardened, might show 95 to 98 scleroscope, file hard, Rockwell C-59 to C-61, and yet not be as satisfactory in service as the chilled part. The only machine left which would give us a better picture of the depth of chill is the Brinell with its 6600-lb. applied load, but its use would mean the destruction of the piece, so that method is out.

In order to insure satisfactory service results for this part, we follow this procedure: If we have our own foundry, control is rather easy. However, if purchased on the outside, the sources must be reliable and their methods of test such that errors are quickly corrected. When received in the automotive plant, this part will be file tested 100%, approximately 5% tested with Rockwell in some area that does not affect its serviceability, and a few tappets broken at random to check the chill-depth.

One could go on enumerating specific cases which would show that despite all our testing methods and the refinements which various instrument manufacturers have introduced, a universal tester is still a long way off. Actually we are rather crude in our methods.

Hardness Conversion Tables

With regard to hardness conversion tables: Many have been published, but personally I do not think they should be used to compare the value of two or more instruments in the inspection of a part. It is the belief of many, and I am in accord, that hardness or physical limits should be set up on the basis of the part itself and the specific testing machine, and not attempt to use conversion tables between one scale of hardness and another, between hardness and tensile strength, endurance, machinability, or wear resistance, unless the metallurgical department has worked out a suitable ratio for the items concerned.

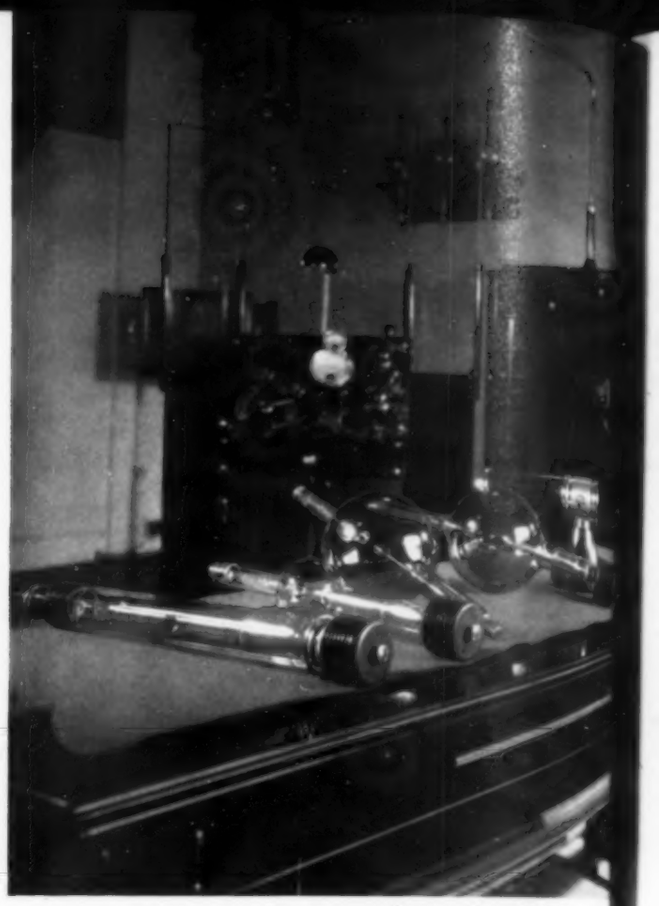
To show the unreliability of comparative hardness tables, we fabricated a number of 1-in. test blocks from forgings or round bar stock 1 in. diameter. These were pack annealed at 1600° F., then quenched and tempered so as to give various Brinell hardnesses. The table gives the results obtained on several types of S.A.E. steels in common use.

X-Rays

Among the

Metals

By Ancel St. John
Vice-President and Consulting Engineer
St. John X-Ray Service, Inc.
Long Island City, N. Y.



Courtesy General Electric X-R

Large X-Ray Tubes of Various Designs

SEVERAL CONTRIBUTIONS to the American Society for Metals have been stimulated by the ability of X-rays to let us "eat our cake and have it, too." No other method of non-destructive testing is able, on the one hand, to disclose so much accurate information concerning the distribution of material within the body of an object as is furnished by radiographic examination; or, on the other hand, to throw so much light on the mysteries of atomic arrangement responsible for the characteristic properties of materials, as is shed by diffraction analysis.

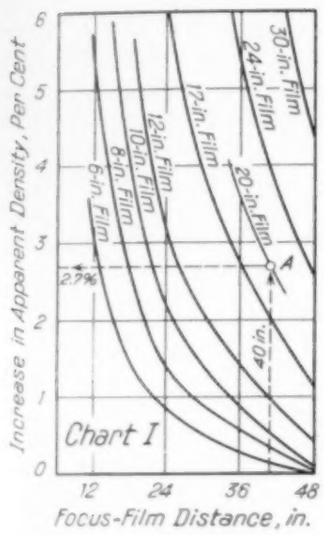
So it is fitting that the next edition of the Metals Handbook include a comprehensive survey of the essential principles and practice of X-ray testing. Extracts from this article by Kent R. Van Horn appeared recently in METAL PROGRESS, (August issue). These treat only of the radiographic aspect, and a few high-lights are worth recalling.

For a long time after X-rays were first detected by Roentgen in 1895 their field of usefulness to industry was very restricted. Limitations of equipment, particularly of the partly evacuated tubes in which the X-rays were produced, required exposures intolerably long for commercial thicknesses of metal. The introduction of the modern, highly evacuated tube just before the War, accompanied by well designed power plants and other electrical accessories, was the beginning of the present era, but the field of usefulness was still very restricted. The writer of this review, for instance, in 1918 secured for the National Carbon Co. the most powerful equipment then available, but it had a working limit of about one inch of steel. Beyond that, exposures were still unduly long. This limit was raised to three inches in 1922 with the installation at the Watertown Arsenal of a 200,000-volt unit. About four years ago the limit was boosted to four inches with 300,000-volt equipment and in 1935 the penetration of steel was increased to five inches by going to 400,000 volts.

Improvements in accessories and methods kept pace with these advances in penetrating power. Faster films and more efficient intensifying screens, by reducing exposure times, assisted in lowering operating costs. Selection of the appropriate exposure time still remains largely a matter of individual experience, though exposure charts such as described by Herbert R. Isenburger in *Transactions*, September 1935, guide to a more intelligent and rapid choice of operating conditions.

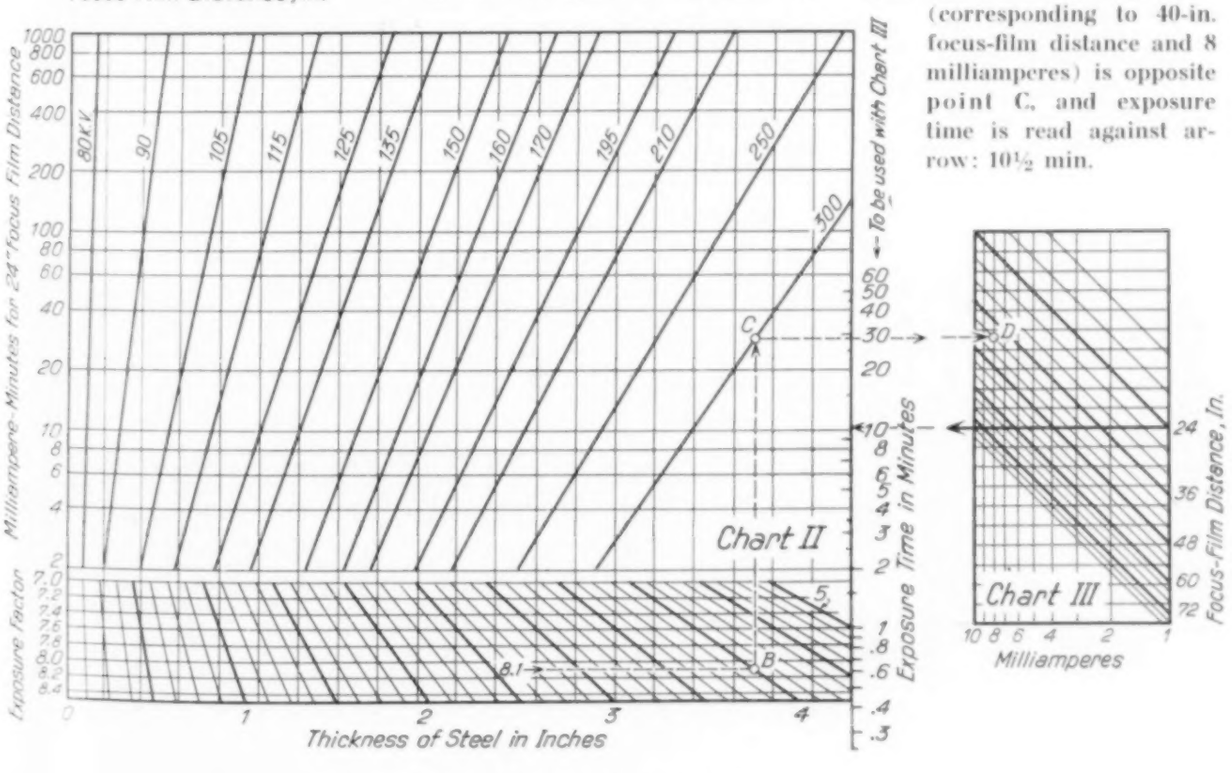
From 1922 to 1931 the major industrial use of X-rays was the examination of steel and other castings. An outstanding instance was the routine inspection of all castings for a 1200-lb. steam-electric plant. In other cases pilot castings have been examined until a satisfactory foundry technique was developed. After 1931 the foundrymen themselves became more interested in the possibilities of X-ray inspection and control. Apparatus now exists in foundries producing alloy iron, steel and light alloys, where it is used eight or nine times to develop casting technique to one time for routine inspection. But when complete inspection is warranted, as for severely stressed fittings in high pressure, high temperature systems, heat resisting retorts, or airplane parts, it is invaluable. Thus one manufacturer of heat resistant furnace fittings, retorts and the like makes sure that no dangerous sub-surface defects exist in castings and so assures increased life in service. He used nearly 1,500,000 sq.in. of film in 1935.

The ability of X-rays to disclose the character and location of injurious defects in fusion welds was recognized by the U. S. Navy in 1930 and later by the American Society of Mechanical Engineers and the American Petroleum Institute. Since the A.S.M.E. code governing boiler drums and unfired pressure vessels was modified in 1931 to permit welded construction (provided the seams were completely inspected with X-rays) this method of construction has progressed phenomenally. The far-sighted manufacturer for whom in 1930 the writer installed the original X-ray equipment for inspection of welds used more than 24,000,000 sq.in. of



Isenburger's Exposure Chart

Solution is given of this problem: "Find correct exposure on 20-in. film at 40-in. focus-film distance for 4-in. boiler plate of density 7.85; 300,000-volt tube, 8 milliamperes." In Chart I find intersection of 40-in. film distance with curve for 20-in. film (point A) and take out 2.7% at left. Increase given density 7.85 by 2.7% making the apparent density 8.1. Find intersection of 8.1 with 4-in. steel on Chart II (point B), project upward to voltage of tube (point C on 300 line). Adjust Chart III so that point D (corresponding to 40-in. focus-film distance and 8 milliamperes) is opposite point C, and exposure time is read against arrow: 10½ min.



film on a single job — that is, the 75 miles of welded seams in the penstocks at Boulder Dam. Six years later, instead of one manufacturer with one equipment, 34 companies interested in boilers and pressure drums have a total of 48 equipments, with which more than 7,000 vessels aggregating more than 150 miles of welded steel joints in plate ranging from 0.25 in. to 4.82 in. thick have been examined radiographically. Furthermore, the confidence in the serviceability of properly welded seams has been reflected in the increasing popularity of fusion welded buildings and heavy equipment.

X-Rays for Foundry Control

A revolutionary change, like that from riveted to welded construction of pressure vessels, does not seem likely in the foundry industry. Thus there is no urgent demand for introducing an X-ray inspection requirement into the various specifications for castings, even though from time to time such is required for a particular installation. Beyond that, the good sense of the maker of castings determines whether or not he avails himself of this powerful tool for improving and maintaining the quality of his product. Such a profitable use has been described by F. K. Ziegler and D. W. Boland in METAL PROGRESS, December 1934. This article gives among other things a series of excellent pictures of typical defective conditions. These authors say:

"In regular production no attempt is made to X-ray every casting. . . . An order for several hundred small parts . . . would be checked by radiographing a reasonable percentage picked at random. If any castings are found defective all those from the same heat or made by the same molder are segregated and examined. This not only protects the customer but often enables us to determine the cause of the trouble.

"Castings from all new patterns are X-rayed to determine whether the foundry practice is correct; when changes are necessary, their effects are rechecked. All pressure castings such as carburizing retorts, valves, fittings and pump parts, all containers for molten salts or lead are radiographed before shipment (as are practically all sizable castings) at those points where defects would be most likely to occur.

"Use of radiography for final inspection causes everyone in the foundry to take greater care in the manufacture of the castings. If the molder knows that careless work on his part is going to be discovered, even though the effects of this carelessness are hidden to the eye, he will take every precaution known to him to avoid any irregularities in the finished product. Despite a number of opinions to the contrary, the writers feel that the love of craft is still present in most high class workmen. If their shortcomings are called to their attention, they will do anything reasonable to correct them."

There have been few better expressions of the true value of X-ray inspection. And it is not from anyone interested in selling X-rays!

The value of X-ray inspection is further exhibited in a later article by one of these authors in June METAL PROGRESS which closes:

"All the castings described in this article were scrapped on account of the evidence presented by the X-ray films. Consequently, the defects shown may be considered as worse than average. Not a single casting, however, with possibly one exception, would have been rejected by the evidence of careful visual examination. It is of course not necessary to X-ray castings with visible defects.

"A large amount of evidence gathered over a period of years and not easily presentable in printed form, shows conclusively that the X-ray does three things: (a) It shows all defects that are known to affect the life of an alloy casting; (b) it is easily adaptable to irregular surfaces and sections; and (c) it differentiates sharply between defects of different character.

"As the highest type of inspection medium yet developed for castings, the X-ray apparatus is quite easily controlled, and delivers uniform and understandable results beneficial alike to manufacturer and customer."

The present writer seems to recall having predicted these very things when, as a "voice crying out from the wilderness" he staged an exhibit of industrial X-ray work at the A.S.S.T. Steel Show in Chicago in 1926. He was told then that he was ten years ahead of the times, and is now rather pleased to have the times catch up with him!

Further ideas as to the wide range of usefulness characteristic of X-ray examination of industrial materials is given in a paper by J. R. Townsend and L. E. Abbott on some applications of X-rays to industrial problems as met at Bell Telephone Laboratories (METAL PROGRESS, February 1936). Among the uses discussed are: Checking up on the soundness of test material before embarking on any extensive testing program; improving the technique of die-casting; examination of complete assemblies to assure the correct position of parts.

The above-mentioned articles by Van Horn and by Townsend and Abbott also devote atten-

tion to the use of gamma rays from radioactive material. Because the high penetrating power of these rays is necessarily accompanied by reduced ability to disclose small differences in thickness, their particular usefulness is in the examination of materials too thick for successful penetration by commercially available X-rays. Typical uses are radiography of steel objects from 5 to 10 in. thick, and of wiped lead joints of telephone cable connections.

Protection From X-Rays

The question of adequate protection of personnel, both those handling the radioactive material and those working in the vicinity while it is being used, has provoked some discussion. (METAL PROGRESS, June 1935). The present reviewer may be excused for inserting his personal views at this point. He began active use of X-rays 30 years ago, when the medical and surgical uses of X-rays and radium were still in their infancy, and the danger of bodily injury through unrestricted use was just beginning to be realized. At that time he decided that too much protection would not hurt anyone, but that too little might be dangerous. He has not yet seen any good reason for altering that decision. Indeed, his own medical experience has shown him that some people are abnormally sensitive to these rays and would be seriously burned by what is ordinarily considered a "safe dose," and he still feels that a ton of lead is better than a single burn.

Diffraction Analysis

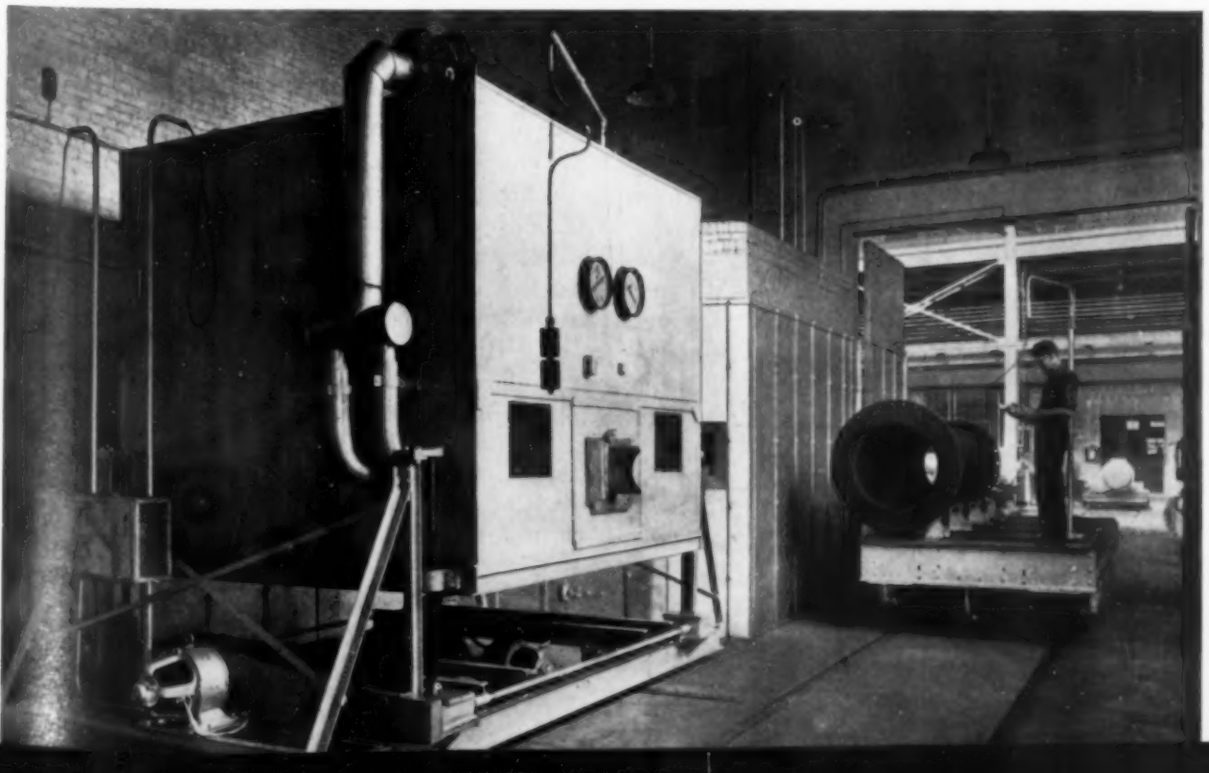
Extracts from the portion of the Metals Handbook which will treat of X-ray diffraction analysis have not yet been published. In this field the contributions of X-rays to the credit side of the profit and loss account are less tangible than those derived from radiography, the materials examined are not expressed in tons, or miles of joint, the film used does not run up to millions of square inches. But the intangible value of the more precise information now available, thanks to X-ray diffraction studies, concerning the interatomic relations in alloy materials is thoroughly recognized.

In some quarters more attention is now being paid to the "eat your cake and have it, too" characteristic of X-ray diffraction analysis. A typical instance is the study of metal at high temperatures presented by Norman P. Goss in METAL PROGRESS, October 1935. A specimen, in the form of a ribbon or wire, is mounted once and for all on the axis of the diffraction cassette so that the small area upon which the fine X-ray beam impinges remains unchanged throughout the entire cycle of temperature changes under investigation. As good diffraction patterns can be made in 10 to 15 min. and a new film can be put in place in a minute or so, it is possible to secure what amounts to a series of "stills" showing the modifications in atomic arrangement as the temperature changes.

In practice it is usually sufficient to take patterns at selected temperatures while a speci-

Radiographic Installation at South Philadelphia Works, Westinghouse Electric & Mfg. Co.

Room for Tube and Power Plant at Left, Control Room at Rear Center and Battery-Driven Truck Under Push Button Control for Handling Work to Be Examined



men is heated by slow steps to, say 2300° F., and cooled again. The knowledge that during such a cycle there has been no change in the *actual atoms* under observation, that any changes in the patterns are properly attributed to modifications of atomic arrangement while any persistent characteristics in the patterns are really due to persistencies in atomic arrangement, makes it possible to state positively, for instance, that one preferred orientation in a rolled complex 16% chromium steel is stable at both room and elevated temperatures while a second is developed during the heat treatment. By holding a given temperature over a series of exposures the stability of the material can be determined. By modifying the atmosphere in the cell containing the specimen the effect of various gases can be studied.

These are exceedingly practical questions, for both production and sales departments.

An effective attack on a more theoretical problem — though it, too, has practical aspects — is presented by a diffraction analysis study of iron-chromium-silicon alloys by A. G. H. Andersen and Eric R. Jette in *Transactions*, June 1936. This painstaking study used exceptionally pure metals to secure alloy specimens containing less than 0.02% carbon. More than 70 compositions were prepared and studied. Specimens were powdered, sealed in small evacuated tubes and put through the desired heat treatment. Diffraction patterns of samples taken from these heat treated specimens were then made at room temperature. In this way the data representing the interatomic parameters and the regions characteristic of the various crystalline phases were developed for the iron-rich solid solutions.

Some equally important papers on the X-ray diffraction analysis of metals are to be presented at the forthcoming convention. One is by D. McLachlan and Wheeler P. Davey on "An X-Ray Study of Preferred Orientation in Pure Cold-Rolled Iron-Nickel Alloys." Very pure iron-nickel alloys, up to 22% nickel, were reduced by cold rolling, starting from annealed ribbon. These were submitted to X-ray diffraction analysis and the patterns studied to determine the effects produced upon the preferred orientation by variations in composition, variations in total reduction in thickness, heavy versus light reductions per pass, and rolling temperature. Further patterns were prepared to find out how deeply these effects extend below the worked surface.

The findings are expressed through stereographic pole-figures, and theoretical equations are suggested which may be capable of predicting the experimental results. The conclusion of particular importance from a practical point of view is that "below a very thin surface skin, the general type of preferred orientation is the same for all our rolled samples, and the degree of preferred orientation depends only upon the per cent total reduction."

Utility In Predicting Fatigue

Charles S. Barrett will report an investigation to evaluate the practical usefulness of X-rays in the study of fatigue failure, using as criteria of impending fracture various possible changes in the character of X-ray diffraction patterns. Several materials were tested; some specimens were examined after breakage when prior stressed for a great many cycles below the endurance limit, others after breakage when prior stressed for fewer cycles above that limit. The results can be summarized as follows:

1. Radial widening of the lines in the patterns is so small that this method is unsuitable for practical control of fatigue testing.
2. The appearance of spot patterns is a better but not entirely satisfactory qualitative indication of increased stress.
3. "There appears to be no hope for an accelerated fatigue test involving X-ray patterns."
4. "X-ray diffraction is not a convenient method of investigating stress concentrations as the volume of material at maximum stress is small and is frequently located in the cold-worked surface layers that must be removed by etching before X-raying."
5. "X-ray determinations of depth of cold working agree satisfactorily with other methods which, though more convenient, are less generally applicable."

This paper includes an extended summary of prior work along this line, which has been rather contradictory. While the third conclusion may be justified, it still should not deter budding geniuses, or even older heads, from evolving methods perhaps more direct and delicate — unless, of course, other methods of predicting the imminence of fatigue failure are so certain and convenient that another method would be superfluous. The fourth conclusion, indeed, suggests that there is still hope, for it is within the bounds of possibility that changes taking place in the cold-worked surface determine when and where failure eventually occurs.

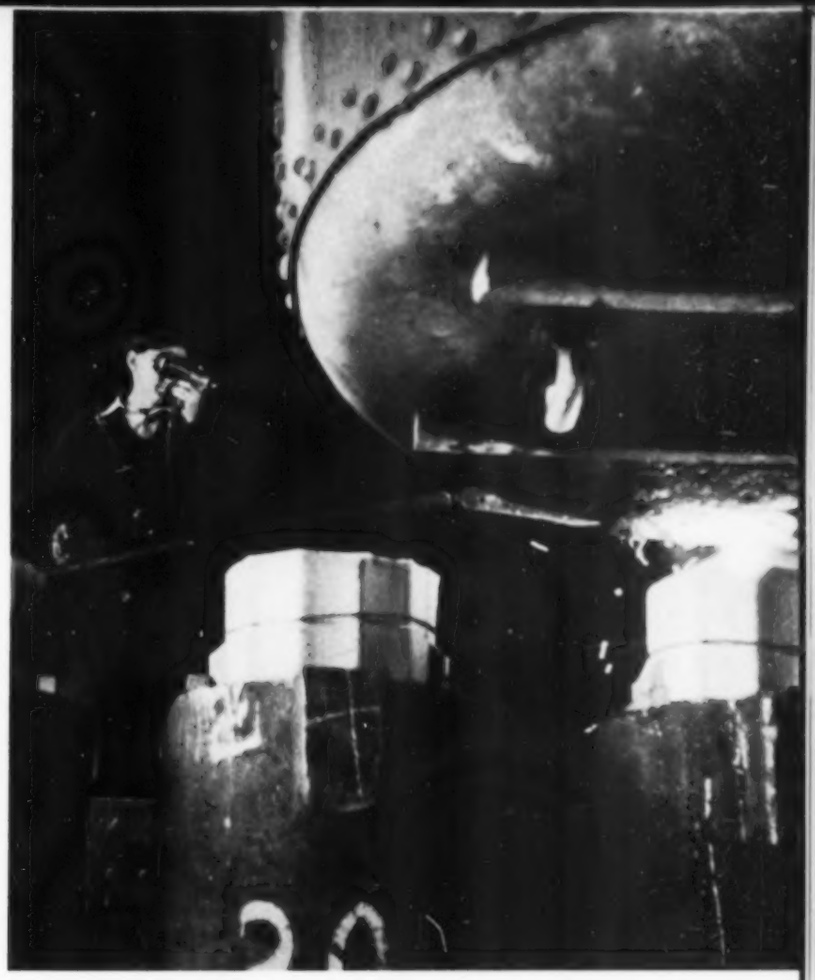
Pyrometry

Thermoelectric

Optical

and

Radiation



An Optical Pyrometer Is the Only Instrument for Checking the Temperature of Steel as it Goes Into the Mold—an Important Detail of Pit Practice

AN EXTENSIVE ARTICLE on thermoelectric pyrometry has been prepared for the forthcoming edition of Metals Handbook by a Subcommittee whose chairman is Kirtland Marsh. Optical pyrometers and total radiation pyrometers are also discussed by P. H. Dike, chief of the physical division, research department, Leeds & Northrup Co. From these two articles have been taken the following Handbook extracts.

Thermocouples

Thermoelectric pyrometry utilizes the fact that a junction of dissimilar metals, when heated, will generate an electromotive force proportional to the temperature. Galvanometers, millivoltmeters and potentiometers are used to measure the electrical effect, and hence the temperature.

The number of metals and alloys suitable for commercial use in thermocouples is rather limited for they must be resistant to oxidation, recrystallization, melting and contamination at high temperatures and at the same time develop a high emf. They are as follows: Platinum, platinum with either 10% or 13% of rhodium, chromel (90% nickel, 10% chromium), alumel (95% nickel plus manganese, silicon and aluminum), constantan (60% copper, 40% nickel), iron, and copper.

Platinum vs. platinum-rhodium thermocouples may be used up to a temperature of 3000° F. but they are easily contaminated and must be suitably protected at all times. Continuous subjection to temperatures above 2800° F. is not recommended.

Iron-constantan thermocouples oxidize readily at temperatures above 1200° F. while the calibration of chromel-alumel couples is subject to change when exposed to a reducing atmosphere. Iron-constantan thermocouples will generally have a longer life and be more satisfactory than chromel-alumel couples in a reducing atmosphere up to 1800° F.

Chromel-alumel thermocouples will generally be more satisfactory than iron-constantan thermocouples in oxidizing atmospheres from 1000 to 2000° F. Chromel-alumel thermocouples may be used intermittently up to 2300° F.

Copper-constantan thermocouples are satisfactory for continuous use up to the range between 600 and 700° F. and for intermittent use up to 900 or 1000° F.

Alternately reducing and oxidizing conditions are detrimental to any base metal thermocouple and the life of any of the base metal thermocouples will be relatively short when exposed above 2000° F. continuously.

The temperature-emf. values for iron-constantan thermocouples as furnished by the several pyrometer manufacturers vary because of slight intentional differences in the chemical composition in the constantan used and therefore are generally not interchangeable. The same is true of copper-constantan thermocouples.

The temperature-emf. values for the several different thermocouples mentioned above may be readily obtained from the pyrometer manufacturers. A new determination of the values for 50 heats of chromel and alumel has recently been made at the Bureau of Standards, and the results described by W. A. Gatward in METAL PROGRESS, March 1935. These alloys have been made under standardized and controlled conditions for over 20 years, and their present uniformity and reproducibility is remarkably high.

Where a thermocouple cannot be used for the measurement of high temperatures, some form of radiation pyrometer is employed. Such measurement is based on the fact that the intensity of the radiation emitted by a hot object increases as its temperature is raised. If the object is hot enough to produce visible radiation, both the intensity or brightness of the radiation and also its color change with changing temperature, letting the skilled observer estimate the temperature approximately by visual inspection.

Radiation Pyrometry

The radiation pyrometers in common use may be divided into two classes. If the measuring instrument totalizes the heating effect of all the radiation that it receives from the object whose temperature is being measured, it is known as a "total radiation pyrometer" or simply a radiation pyrometer. If it measures the intensity or brightness of the radiation received from the object, in a narrow band of the visible spectrum, it is known to the industry as an optical pyrometer.

"Total radiation pyrometers" are designed to collect a fixed fraction of the energy radiated from a definite area of the hot body whose temperature is to be measured, absorb this energy in a receiver and measure the heating effect thus produced in the receiver — commonly a blackened disk to which are attached the junctions of one or more thermocouples. These junctions are seldom heated over 210° F., and since they are the heart of the radiation pyrometer, most of the troubles encountered in practical use may be traced to them, for the elements have been chosen for high thermoelectric power rather than for stability and strength.

Radiation pyrometers use either a spherical mirror or a lens to focus the energy rays on the thermocouple elements. Either type may have a fixed or a variable focus, the latter to accommodate changes in distance of the object. Mirror types can measure lower temperatures than the lens types, but the lens type is smaller and does not require as large a field of view at a given distance.

Theoretically, radiation pyrometers may be used throughout the entire temperature range. Practically, they are limited at 1000° F., and commonly used above 1500° F. Under favorable conditions, an accuracy of 10 to 25° F. is obtainable in the range 1000 to 3000° F.

Optical Pyrometry

An optical pyrometer is a photometer — a telescope sighted on the body, the temperature of which is being measured, with means for observing simultaneously the light radiated from a standard source and of matching the two in brightness. There are two general types of optical pyrometers:

(a) Variable Intensity Comparison Lamp Type — This type includes those in which the brightness of the comparison light (an electric lamp) can be varied so as to match the apparent brightness of the light from the body under test, the brightness of the comparison lamp being at all times definitely related to the current which passes through it. It requires a precise means of controlling and measuring the filament current, the filament resistance, or the drop of potential through the filament.

(b) Constant Intensity Comparison Lamp Type — This type includes those in which the comparison light is maintained at a constant brightness and the brightness of the light from the hot body is cut down to match it by means of an absorbing device, such as a glass wedge.

Photo by John P. Mudd for The Midvale Co.

The Human Eye Is a Marvelous Pyrometer — When Checked Constantly by an Accurate Instrument

an iris diaphragm, or a polarizing prism. An electric lamp is usually employed for the comparison source and requires means of standardizing the filament current at only one value, resulting in a more compact and lighter instrument. A disadvantage of this type is that all brightness matches must be made at the relatively low intensity corresponding to the lowest temperature to be measured with the instrument, or else the comparison lamp must always be operated at its maximum brightness, thus shortening its life.

The useful range of the optical pyrometer begins at 1200 to 1500° F., since the radiation emitted by bodies at lower temperatures is of low luminosity, and balances are difficult even in a darkened room. No upper limit can be set. The Bureau of Standards will certify the readings of a commercial type of disappearing filament variable current optical pyrometer to ±9° F. up to 2550° F.; ±18° F. from 2550 to 3300° F.; and ±36° F. from 3300 to 5150° F. Readings with the same instrument under practical shop conditions can be repeated by an operator to ±5° F. It does not necessarily follow that all types of optical pyrometers can be operated within the same limits of error.

Relative Advantages

Thermoelectric pyrometers may be satisfactorily used for measuring temperatures from about −330° F. to about +3000° F. The equipment is relatively inexpensive, and easily adaptable to automatic control of fuel valves and other items of furnace regulation. It may be installed so as to give information about exact temperatures at a small point, and (aside from contamination) is independent of smoke and other obstructions to radiation and optical pyrometers.

The advantages of the *optical pyrometer* include its use for measuring high temperatures, and measurements (also at lower temperatures) on inaccessible bodies, moving bodies, small bodies whose temperature would

be affected by the attachment of a thermocouple, and for occasional readings when the installation of a thermocouple would not be economical or feasible. Other advantages are that no part of the instrument is exposed to destructive heating effects, and that the indicated temperature is related directly to the temperature of the heated body under test and not to the temperature of some adjacent body (for example a thermocouple), which is assumed to be at the same temperature.

The principal disadvantages are the ease with which errors may be introduced by absorbing screens of smoke or incandescent gases between the observer and the object under test, and the fact that with most instruments each reading is the result of a photometric match made by an individual observer, and affording an opportunity for dishonest or prejudiced readings, as well as accidental errors. Errors are also introduced by uncertainty as to departure from "black body conditions."

Radiation pyrometers, as compared with thermocouples, have the following relative advantages:

(a) No contact with the hot body is required, making it possible to measure the temperatures of moving objects, such as billets or cars in kilns.

(b) The time lag is generally much less than that of a thermocouple, particularly when the latter must be protected by a heavy ceramic or metal tube.

(c) The instrument is not subjected to deterioration through exposure to the high temperature measured, nor through contamination by furnace gases.

Their disadvantages are:

(a) Relatively large sources are required.

(b) Corrections must be applied to the usual "black body" calibration when such conditions do not exist in practice.

(c) The accuracy obtainable is generally less than with thermocouples.

(d) Higher first cost.

Advantages of the radiation pyrometer, relative to most optical pyrometers, are:

(a) The personal element does not enter into the measurement.

(b) Direct reading indicators, recorders, and controllers are available.

(c) Lower temperatures can be measured.

On the other hand, the disadvantages are:

(a) Larger sources are necessary.

(b) Corrections for deviations from "black body" conditions are larger and less accurately known.

(c) In general the accuracy is lower.

Pyrometer Troubles

Trouble may occur in the thermocouple and its circuit, or in the recorder or measuring instrument. Some of the latter are sealed by the manufacturer; in any event unless the fault is perfectly evident and readily corrected without any chance of endangering the mechanism, the whole thing should be returned to the maker for repair.

Troubles external to the instrument can generally be eliminated by the user if the cause of the difficulty can be located. The following paragraphs enumerate some of the troubles which may be encountered and tell how to locate them.

I. Instrument Does Not Respond Properly to Change in Temperature of Thermocouple

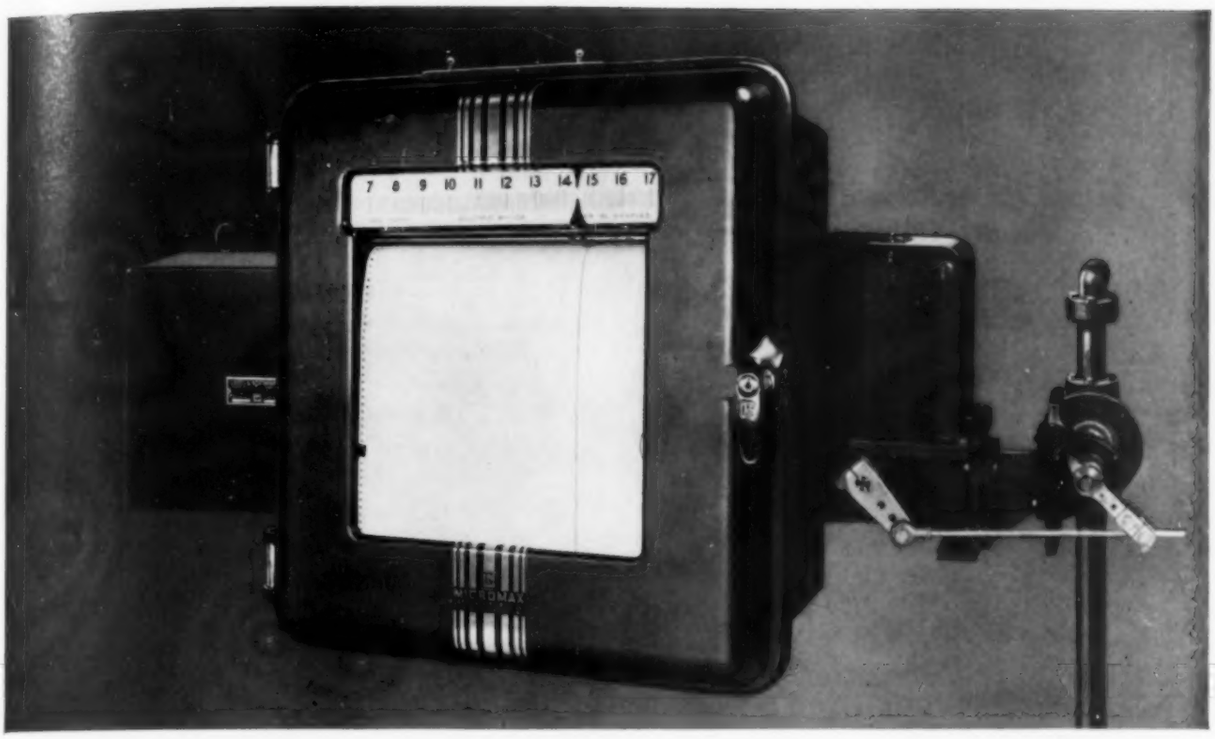
(a) Burned Out Thermocouple — One element of the thermocouple may be completely oxidized or broken. This should be apparent from examination.

(b) Broken Connection — A wire may have come loose from a binding post or one of the leads may have broken at a soldered connection or elsewhere. The first should be apparent on a visual examination but the second might require that the instrument be disconnected and the circuit rung-out with a battery or magneto and bell. If the circuit external to the instrument is found to be complete and the thermocouple in good condition there may be an open circuit in the instrument. This can be checked by applying an emf. from a potentiometer or another thermocouple to the binding posts of the instrument in question. Check all battery connections and sliding contacts. If the trouble is definitely located in the instrument, call in the manufacturer or return the instrument to him.

(c) Faulty Selector Switch — If a selector switch is used, the trouble may be in the switch in which case the instrument should respond properly when the thermocouple leads are connected directly to the instrument.

(d) Short Circuit — Make sure the leads or thermoelements have not become short circuited in the terminal head of the thermocouple. A short circuit may exist between the instru-

(Article continued on page 172)



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Pyrometers

(Article starts on page 167)

ment and thermocouple. Disconnect the instrument and thermocouple and ring-out the circuit, which should be open.

II. Instrument Reading Is Erratic

The reading of the instrument may vary up and down the scale or if a selector switch is used the instrument may show one reading at one time and a different reading at another, even though the furnace temperature has not changed.

(a) Loose Connection — Make sure that all binding posts and other connections are tight, that all sliding contacts are clean, and that the themoelements are not loose or broken at the weld or elsewhere. If the weld at the hot junction is suspected, pinch it with a pair of pliers while still hot and note if the instrument reading changes suddenly. The leads may be broken at some point and still make intermittent or poor contact, in which case pulling or shaking the leads may locate the defect.

(b) Faulty Selector Switch — The switch contacts may be poor, due to dirt or loose parts, and this should be revealed by operating the switch. Tighten all parts, clean thoroughly, and if the contacts appear to have been greased supply a thin coating of fresh vaseline. If the switch is completely enclosed, not built for ready opening, a service man should be called in to make the repair, or the instrument returned to the manufacturer.

(c) Fault in Instrument — Test for an open circuit in the instrument as described in Section I, *(b)*. In the case of a millivoltmeter the instrument pointer may be dragging on the scale. Some part of the moving system, or, in the case of a potentiometer, some part of the galvanometer such as the coil or a fiber of insulation on the coil may be making contact with some part of the instrument, or a loose piece of magnetic material on one of the magnet poles. Rap the instrument case sharply with the knuckles and note if the pointer jumps to another position and remains there. It is sometimes possible to dislodge the obstruction by repeatedly making the pointer deflect clear across the scale. This can be done by intermittently connecting the instrument to a poten-

(Please turn to page 174)

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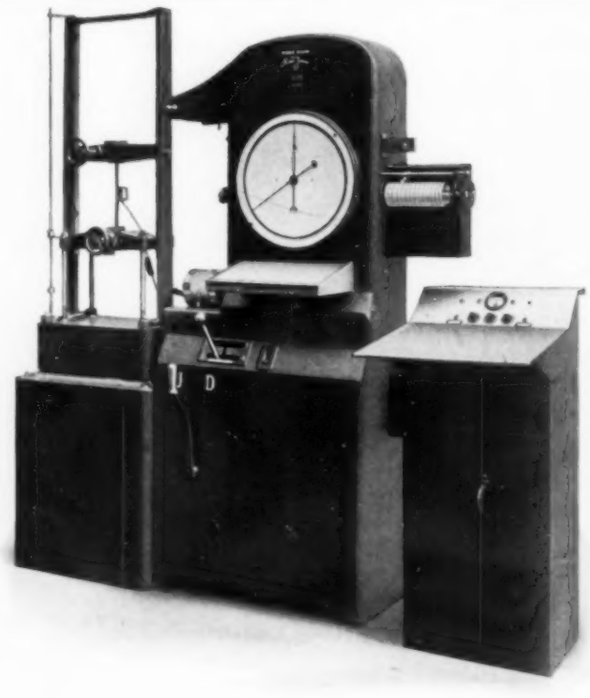

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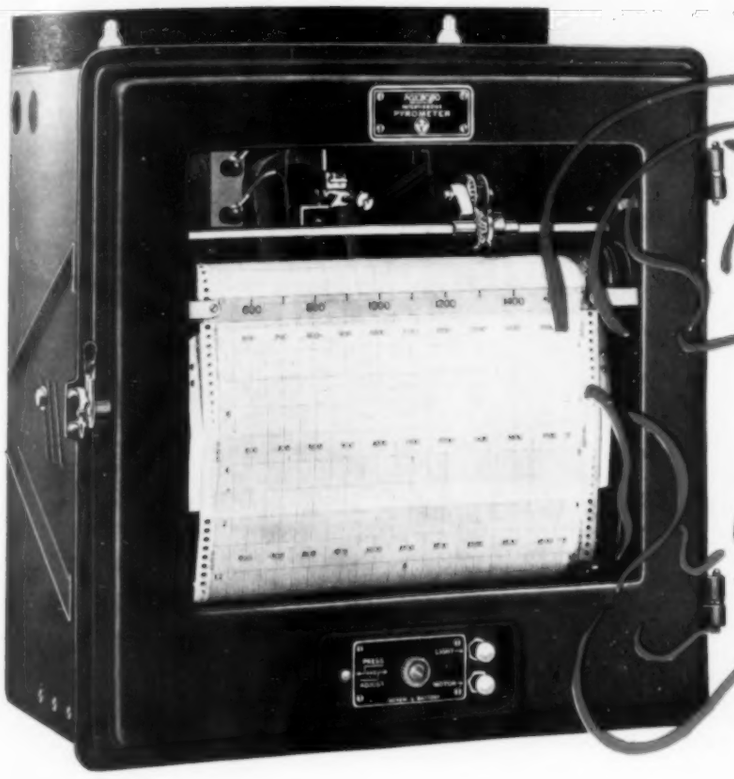

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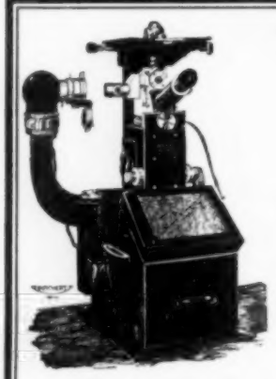

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PYROMETERS

(Article starts on page 169)

tiometer or to a thermocouple hot enough to cause full scale deflection.

If the pivots of the moving coil of a millivoltmeter have become dull, there may be enough friction to cause the pointer to stop short of the actual temperature. Rapping the instrument case with the knuckles will generally cause the pointer to move nearly to the correct temperature. This trouble can only be corrected at the factory.

III. Instrument Reads Low

(a) Zero and Cold Junction Settings — Check the zero and cold junction settings as instructed by the manufacturer. If automatic cold junction compensation is provided, check the setting and adjustment of the compensator; the instrument should read the temperature of the temperature-sensitive element of the compensator with the thermocouple terminals on the instrument short-circuited.

(b) Battery Current — If a battery is used in the measuring circuit, check up on the battery current.

(c) Deteriorated Thermocouple — The thermocouple may have deteriorated by oxidation or otherwise to such an extent that a lower-than-normal emf. is generated. Try another thermocouple.

(d) Wrong Thermocouple — If a thermocouple which generates an emf. other than that for which the instrument is calibrated is connected to the instrument, it will read incorrectly; that is, a chromel-alumel thermocouple connected to an instrument calibrated for iron-constantan thermocouples will produce low readings.

(e) Increased Lead Resistance — Some of the individual wires in stranded leads may have broken or been poorly soldered, or the thermocouple may be badly oxidized. Disconnect the instrument and measure the resistance of the external circuit. If it is materially higher than originally, replace the thermocouple and if still high look for trouble in the leads.

(f) Short Circuit Through High Resistance —A short circuit may be through low resistance, as in the case of good electrical contact between the two elements of the thermocouple, or it may

(Please turn to page 186)

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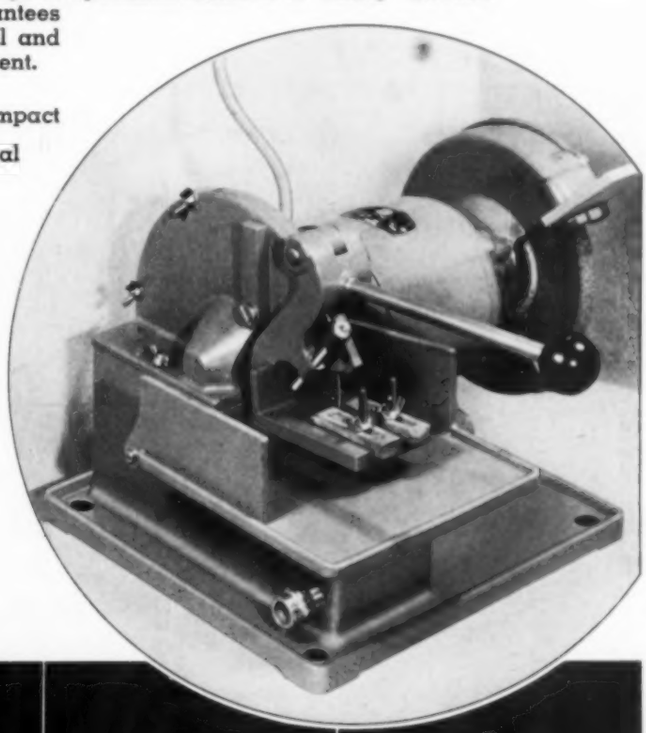

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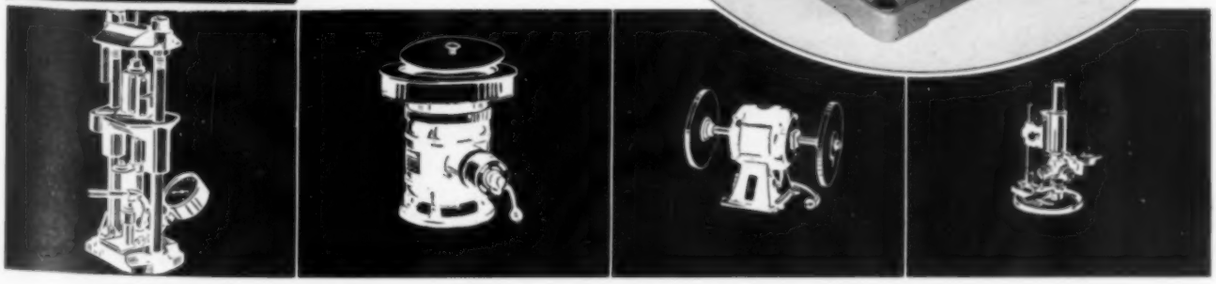

PYROMETERS

(Article starts on page 169)

be through high resistance, as in the case of a poor electrical contact between the elements of the thermocouple or leads. If the first case, the instrument reading will be much lower than the actual temperature, while if the second case the reading may be only a little lower than the correct temperature. Examine the thermocouple and all readily accessible points where such a condition might exist. If this fails, disconnect the thermocouple and instrument and measure the resistance which should be infinitely high. If an ohm-meter is not available, ring-through from one lead to another with a magneto.

A high resistance short circuit may be caused by dampness of the insulation on the leads. Moisture on some insulating materials may set up a galvanic action and cause the instrument to read too high. The previous use of soldering acid may cause the same effect.

(g) Fault in the Instrument — The calibration of the instrument may have changed. This can only be determined by recalibration. A high temperature around the instrument would tend to make the instrument read low but generally not enough to be detected except by a recalibration. If dry batteries are used in or around the instrument, moisture on the paper covers may cause a high or low reading. Note if the reading changes when the batteries are separated from each other and insulated from their support with a piece of glass.

IV. Instrument Reads High

(a) Zero and Cold Junction Settings — See Section III, *(a)*.

(b) Faulty Standard Cell — If the standard cell in a potentiometer has been damaged or has deteriorated, its voltage will be low and a low value of the standard current in the potentiometer circuit will result. This will cause the instrument to read high. Try another standard cell. *Do not test a standard cell with a voltmeter.*

(c) Wrong Thermocouple — See Section III, *(d)*. A 13% alloy platinum-rhodium thermocouple connected to an instrument calibrated for 10% alloy platinum-rhodium thermocouples will produce a high reading.

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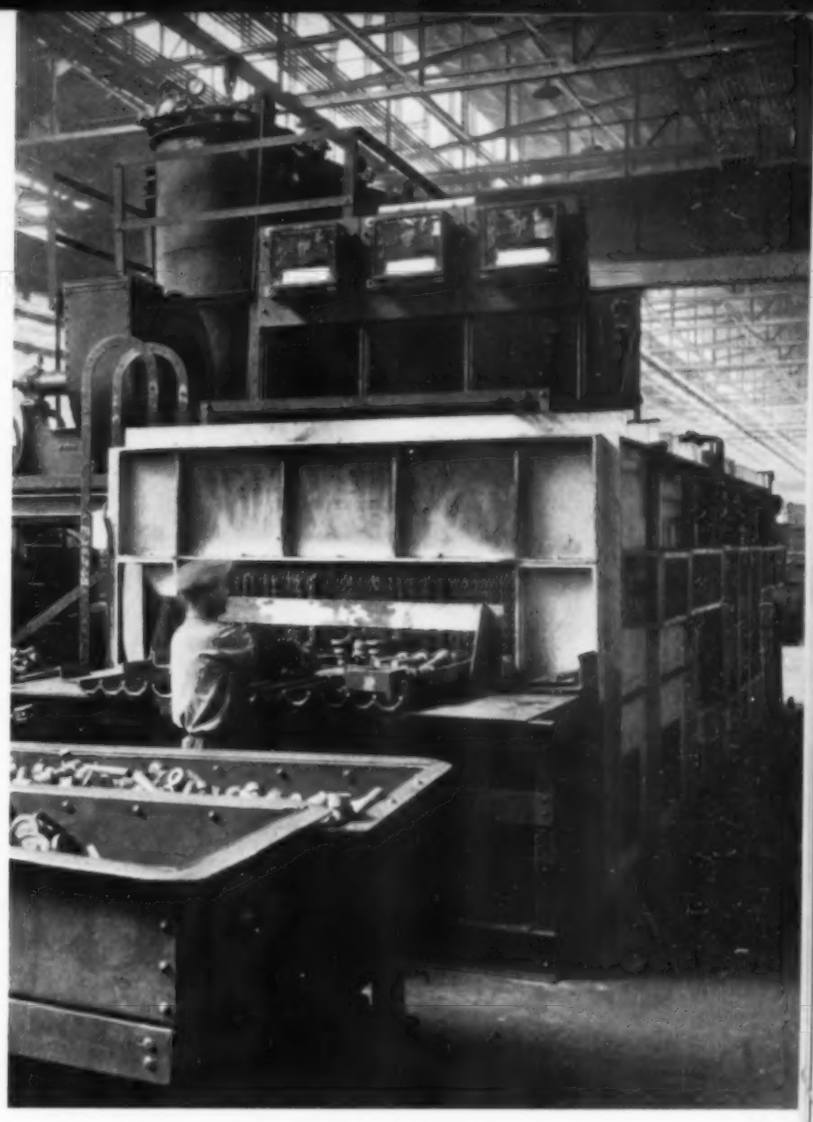


Heat Resisting Alloys Carry the Loads in Modern Heat Treating Furnaces

ALL HEAT RESISTING ALLOYS are essentially alloys of iron and chromium in which the chromium serves to inhibit high temperature corrosion. In addition to iron and chromium, most heat resisting alloys also contain nickel which has been added to intensify the action of the chromium and to enhance the physical properties of the metal. The chromium content varies from as low as 12% to as high as 30%, and the nickel content may be as low as 8% or as high as 65%. Typical compositions in chromium and nickel are as follows; the balance in each alloy being principally iron:

18% chromium, 8% nickel
24% chromium, 12% nickel
28% chromium, 10% nickel
25% chromium, 20% nickel
15% chromium, 65% nickel
15% chromium, 35% nickel
20% chromium, 25% nickel
18% chromium
28% chromium

In the following discussion, alloys containing more nickel than chromium will be referred to as *nickel-chromium* alloys. Those in which chromium predominates will be called *chromium-nickel* alloys and those containing only chromium and iron will be designated *straight chromium* alloys.

Chemical Stability

Of the several alloys available for high temperature service, some are more stable than others in their resistance to chemical attack depending upon the environment in which they are to function. The most common forms of chemical action encountered in commercial heating practice are oxidation, sulphidation, and carburization. These factors acting together or independently may cause premature failure unless they have been carefully considered in selecting the alloy. Under purely oxidizing conditions (hot

combustion gases with an excess of air) any one of the three types of alloys mentioned may be used, the choice depending upon the temperature and the physical properties of the metal at elevated temperature (a subject to be discussed later on in this article).

Under reducing conditions resulting from incomplete combustion (in the absence of sulphur compounds) the nickel-chromium alloys are generally preferred because these alloys do not tend to carburize very readily.

In the presence of sulphur compounds, it is customary to use one of the chromium-nickel alloys. The extent to which sulphur may influence corrosion depends upon the amount present, the temperature, and the form in which it exists, usually SO_2 or H_2S. The subject of high temperature corrosion by sulphur is not well enough understood to permit other than a few general remarks, but practical experience indicates that chromium-nickel alloys are more resistant than nickel-chromium alloys and not infrequently the only alloys that can safely be used in furnaces fired with high sulphur content fuels. In general it is assumed that harmful compounds will be present if the fuel contains in excess of 1% sulphur. It is further the general opinion that the higher chromium-to-nickel ratio is more important under reducing than under oxidizing conditions.

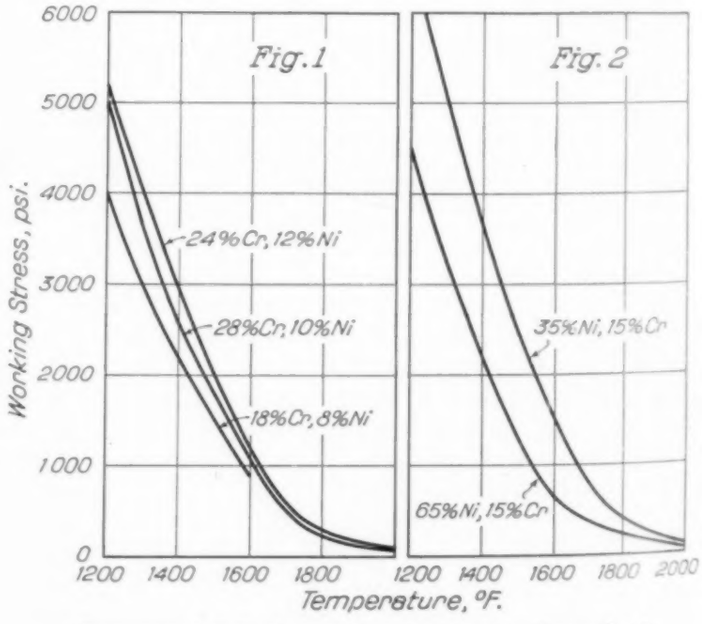
This article was prepared for the 1936 Metals Handbook, with the advice of a Subcommittee of the Recommended Practice Committee with the following membership: O. E. Harder, Chairman; E. C. Bain, F. M. Becket, F. A. Fahrenwald, H. H. Harris, M. A. Hunter, C. M. Johnson, T. H. Nelson, N. B. Pilling, L. J. Stanbery, E. H. Stilwill, F. K. Ziegler, R. D. Van Nordstrand.

High Temperature Strength

Next in importance to the question of chemical stability at high temperature is that of high temperature strength. It would be useless to select an alloy on the basis of high temperature strength alone because the physical strength of the material would be discounted by the loss of section due to progressive surface deterioration where this occurs. Conversely a material offering maximum resistance to corrosion and lacking in high temperature strength would lead to premature structural failure. But where more than one alloy is known to possess adequate resistance to corrosion under a particular set of conditions the choice should obviously be based upon physical characteristics and upon cost.

The straight chromium alloys compare unfavorably with the chromium-nickel and nickel-chromium compositions in the matter of high temperature strength under conditions of heat and sustained loading. For this reason and because they may be subject to embrittlement at temperatures above 1200° F. and to grain growth at higher temperatures, the straight chromium alloys find a limited field of usefulness in applications requiring extremely high temperature resistance.

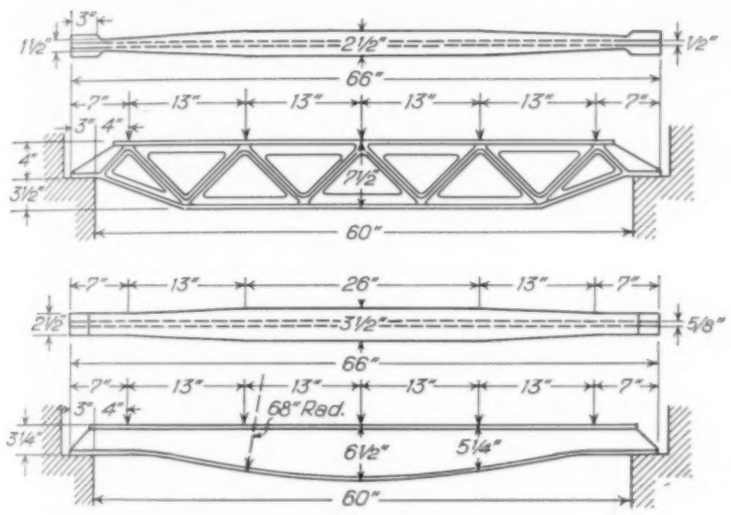
Because of their nickel content the chromium-nickel alloys are in some respects more stable at high temperature than the straight chromium alloys. While these alloys may become less ductile under prolonged heating they do not become actually brittle in their cast forms unless the carbon content is sufficiently high to permit excessive carbide precipitation at the grain boundaries. Brittleness from this



Recommended Design Values for Tensile Strength of Heat Resisting Castings—Includes "Factor of Abuse" as Estimated From Working Life of Many Furnace Castings

cause should not be mistaken for brittleness due to carburization, to which the chromium-nickel alloys are more or less susceptible, the rate increasing as the nickel content is lowered. Carbon exerts a profound strengthening effect in all chromium-nickel alloys which is achieved at the expense of ductility. For this reason it is generally preferable to limit the carbon content to 0.20% max. in the 18% Cr, 8% Ni alloys, to 0.35% max. carbon in the 28% Cr, 10% Ni alloys, and to 0.50% carbon max. in the alloys containing 24% Cr and 12% Ni.

Of the above alloys, the 18-8 material is most susceptible to embrittlement due to carbide precipitation and carburization and for this reason it is not widely used at high temperature in cast forms.



Trussed Beam Weighing 75 Lb. Has Same Load Carrying Capacity as Solid Beam Weighing 120 Lb. and Also Will Have Longer Life Because It Will Be More Uniformly Heated in Service

Design Strength

The accompanying set of curves at left gives recommended design values for safe tensile strength at high temperatures for the most commonly used chromium-nickel alloys with carbon contents limited as indicated above for the various types.

The nickel-chromium alloys and most of the chromium-nickel alloys are essentially austenitic alloys by reason of their high nickel content. Consequently they are more stable at high temperature than the straight chromium compositions. The effect of carbon in promoting brittleness is less apparent in the nickel-chromium alloys although excessive carbon content involves a serious loss in high temperature strength. For this reason nickel-chromium alloy castings are usually produced with a carbon content of 0.40 to 0.70%. Recommended design strength values for the two best known and widely used nickel-chromium alloys are shown in the right pair of curves (Fig. 2).

The design strength values given in these figures have been developed from data largely derived from service installations. Little is known concerning the mechanism of strain at elevated temperature and from data as yet derived it is not possible to assign infallible design strength values to the various commercial heat resisting alloys (of which those already discussed are representative). Obviously "design strength" must comprehend loss of section due to corrosion, which in extreme cases may approximate 10% or more per year. Design strength should also provide a margin of safety in cases of accidental overloading or overheating, which may occur in spite of the most advanced methods of control. Where corrosive conditions compel the use of an alloy having an unstable ("metastable") microstructure, it must be considered that the rate at which transformations adversely affecting the strength of the material take place is a function of *time* as well as temperature, and due allowance must be made for this phenomenon in arriving at a suitable design strength value for a given temperature.

Cases in which premature failure take place due to actual lack of load carrying capacity are fortunately rare. This is due to the circumstance that most heat resisting castings must be designed within practical foundry limitations which generally compel departure from theoretical ideals. But where no such limitation exists the most dependable practice is to employ design values which have been arrived at from accumulated data covering many thousand actual installations where load, temperature, and service life are definitely known and where the "coefficient of abuse" due to the exigencies of operation has been included in consideration of the service life. A design value based on such considerations is the safest practice.

Casting Design

It is always preferable to design a section of symmetrical proportions such as the I-beam, rectangle, or tube instead of channels, angles, and tees which are eccentric to at least one axis. H. Klouman in The Book of Stainless Steels, second edition, p. 637, points out that the eccentric shapes cannot be produced as straight castings due to the effect of unequal cooling in the mold, nor can such sections be put into service after straightening with assurance that they will remain straight. To quote his words, speaking of furnace parts: "Wherever possible it is highly desirable to utilize sections which are symmetrical about two center-lines. Beams with such cross-sections as circles, squares, or rectangles, or I-beams and H-beams resist distortion far better than channels, angles, and tee sections. It is, as a matter of fact, impossible to produce a straight casting from a straight pattern in these unbalanced shapes, due to the irregular way the pieces cool in the mold."

Hollow, circular shapes are well produced as centrifugal castings which are now available in all heat resisting analyses. Centrifugal castings are less subject to residual stresses existing in sand-cast tubular shapes that have contracted while in a plastic condition against a relatively unyielding sand core.

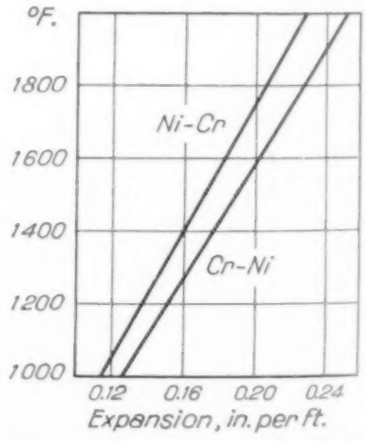
Metal thickness should be as uniform as possible because nonuniformity of integral parts tends to create shrinkage strains and cavities when cooling unequally from the molten state. Such sections are predisposed to warp in service due to different rates of change of temperature in the same casting. For similar reasons solid intersections should be avoided where possible. The effect of shrinkage can be minimized by the use of carefully located chills or preferably by coring through the mass at intersections.

In designing structural elements it is important that the metal be correctly disposed. Trussed girders can frequently be designed more efficiently than solid webbed beams because the lightly stressed metal near the neutral axis of the latter can be used to greater advantage in truss chords and web members operating at full design stress. In operation trussed members permit freer circulation of heat than solid webs and thus have more even temperature distribution. Carefully placed brackets and ribs will often render a light lattice structure as stable as a heavy solid element because dead weight at high temperature is a large portion of the total load creating stress, and frequently exceeds that portion due to externally applied loads. The sketches on page 193 compare a solid and trussed beam having the same load carrying capacity; one weighs 75 lb., the other weighs 120 lb.

Where choice exists as to the size of individual castings it is preferable to use several short pieces instead of one long piece, thus facilitating the casting of lighter metal sections and minimizing the possibility of warpage due to unequal temperature distribution throughout the length of the longer member. Multiple spans designed as continuous beams are objectionable because supporting elements operating at high temperature are always subject to irregular displacements relative to each other and a slight displacement of supports seriously affects the magnitude of the stresses calculated on the assumption of continuity.

Thermal Expansion

In the design of heat resisting castings it is imperative to allow for free expansion of each part. Otherwise, stresses of incalculable magnitude may arise with the certainty of failure or distortion somewhere in the structure. The coefficient of expansion for all heat resisting alloys is not constant throughout a given temperature range but for practical purposes may be considered so. The curves below give average rates of expansion for the chromium-nickel and nickel-chromium alloys included in the preceding discussion.



Thermal Expansion of the High Nickel Alloys Can Be Estimated From the Top Curve; High Chromium Alloys From the Bottom

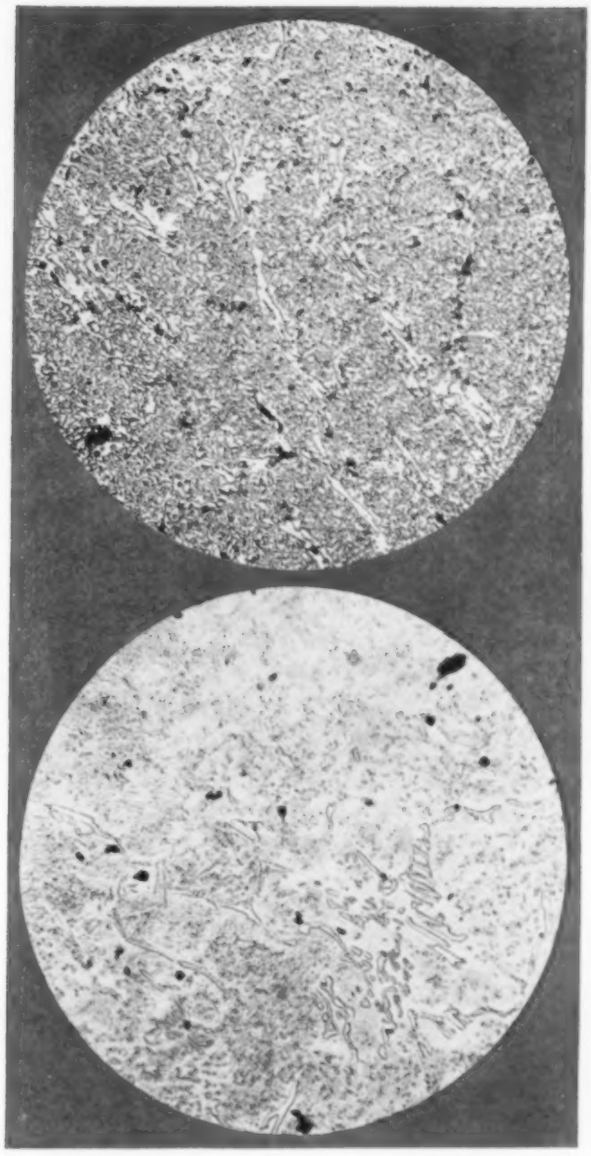
WELDING OF HIGH ALLOY CASTINGS

By F. K. Ziegler
Metallurgical Engineer

and L. B. Haughwout
Radiographer

The Electro-Alloys Co.

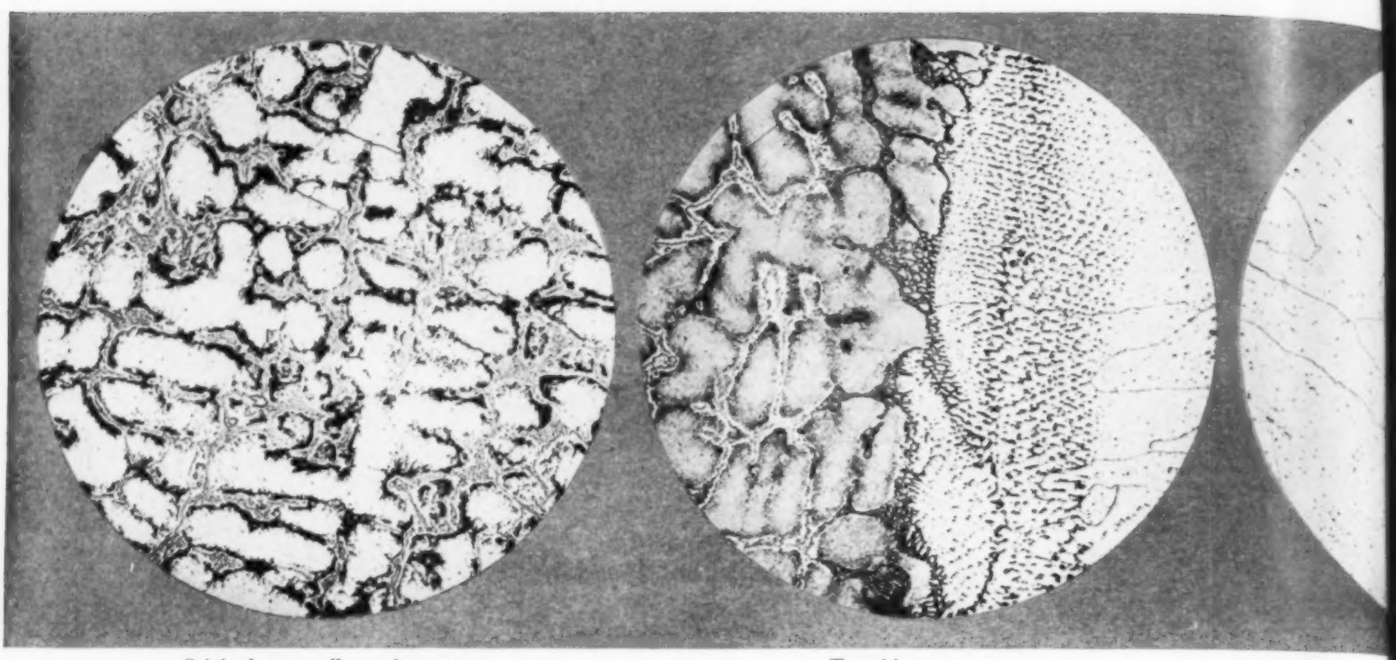
Micrographs by
Union Carbide & Carbon Research Laboratories



Micros at 100 Diameters of Nickel-Chromium Alloy Carburizing Pot After Long Service. Top shows carburized layer about ⅛ in. deep, quickly changing to structure below (taken near outer surface exposed to furnace atmosphere — not carburizing)

DURING the past few years, and particularly since the application of X-rays to the inspection of metals, manufacturers of heat resistant alloys have devoted considerable attention to the improvement of their welding practice. The development of heat treating furnaces in size and complexity (especially those with automatic handling of stock) has necessitated the growing use of structures consisting of several cast parts welded together into a unit too large to cast in one mold. Since these composite castings are usually expected to give several thousand hours' service without breakdown, the welded areas must be able to stand up equally as well as the separate castings which make up the complete structure.

Many users of alloy castings are skeptical about the durability of welds, since they have had experiences with poor welds; they therefore condemn welds generally, holding that they will cause failure before the base castings have given the expected service. Inspection departments of some of these consumers have been instructed to scrap all castings showing evidence of welding other than spotting to improve appearance. This has led to the practice, on the part of the alloy manufacturer, of carefully grinding and sand blasting all welded areas to avoid detection by the inspector. Such actions are naturally not conducive to the best relations between buyer and seller, and it is the purpose of this article to show that welds properly made do not affect



Original cast wall, not in service *Transition zone* *Weld metal, la*

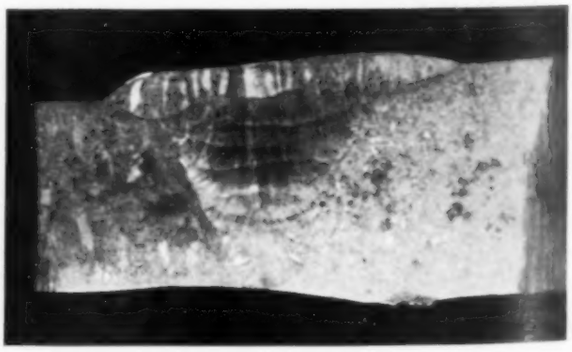
Structures at 100 Diameters Across Welded Joint in 65% Ni, 15% Cr Carburizing Retort

the structure and service life of a nickel-chromium casting.

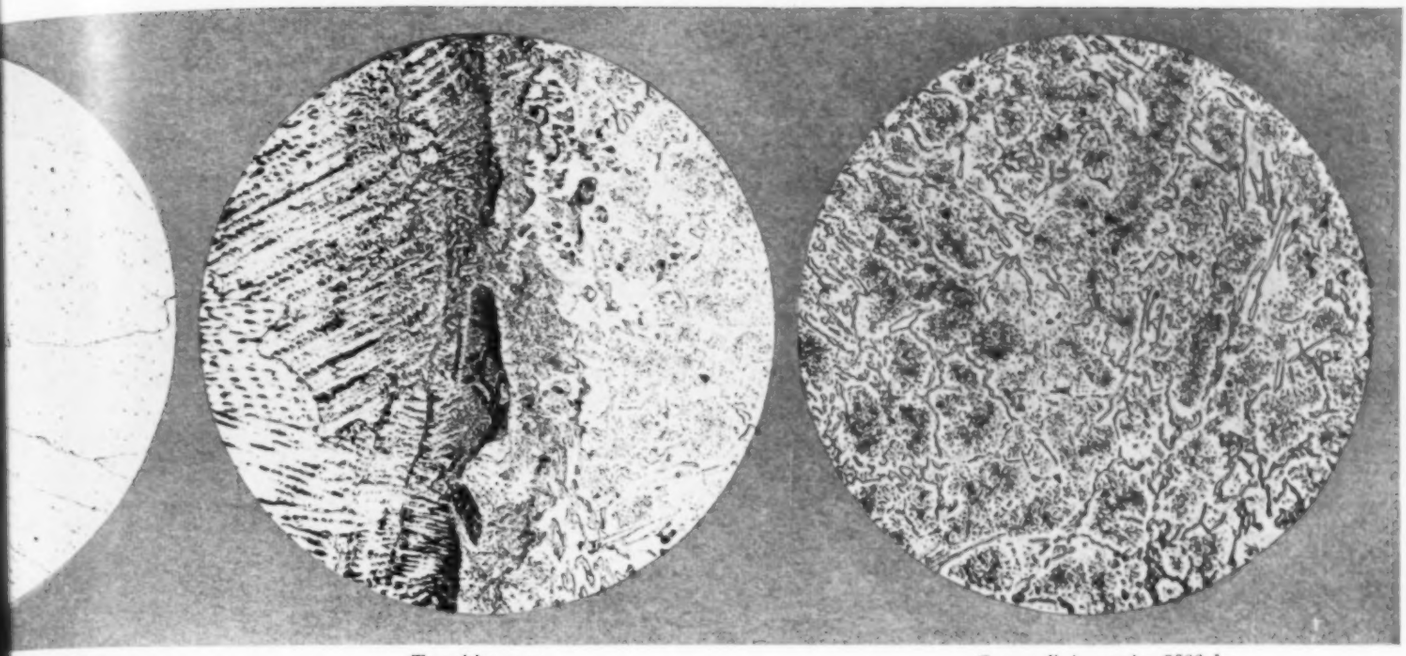
Welding of foundry defects in high alloy castings is general, and accepted as good practice by all manufacturers, with limitations dictated by experience in foundry and welding shop, and to a certain extent by the type of service expected of the casting. Service records of thousands of castings prove that, if a *good* weld is made, it has little if any effect upon the life of the casting. This statement holds good, even though the welding rods or electrodes commonly used are lower in carbon content than the original casting (although the alloy constituents must be substantially the same in chromium and nickel).

The limitations mentioned include the size of the defect and the condition of the metal adjacent to it. If certain types of shrinkage are present, a satisfactory weld cannot be made and the casting must be scrapped. Likewise if the cost of the weld equals or exceeds the melting and molding cost of the casting, no economy will result. The physical condition of the metal adjacent to a defect is the limiting factor in the ultimate quality of a weld. As pointed out previously in METAL PROGRESS (December 1934 and June 1935), high alloy castings are subject to various forms of shrinkage, which frequently do not appear on the surface. These internal flaws may be of such nature that they have no effect upon the life of the casting, yet if they were exposed in the process of removing a harmful area in preparation for welding, would prevent the welder from making a good weld.

Thanks to the X-ray, we are able to discover the exact physical condition of the part adjacent to a flaw and to determine without a doubt whether it is advisable to undertake a repair. A spongy, oxidized area will usually indicate its presence to an expert welder after he starts work on it, but the tendency is to go ahead with the weld as long as there is any chance of completing it, with the result that a poor weld eventually shows up in premature failure of the casting. On the other hand, a competent radiographer can determine by ex-



Micro of Joint in Nickel-Chromium Plate, Slightly Enlarged, Studied in Detail Above



..., low carbon *Transition zone* *Cast wall, in service 8500 hr.*

Structures at 100 Diameters Across Welded Joint in 65% Ni, 15% Cr Carburizing Retort

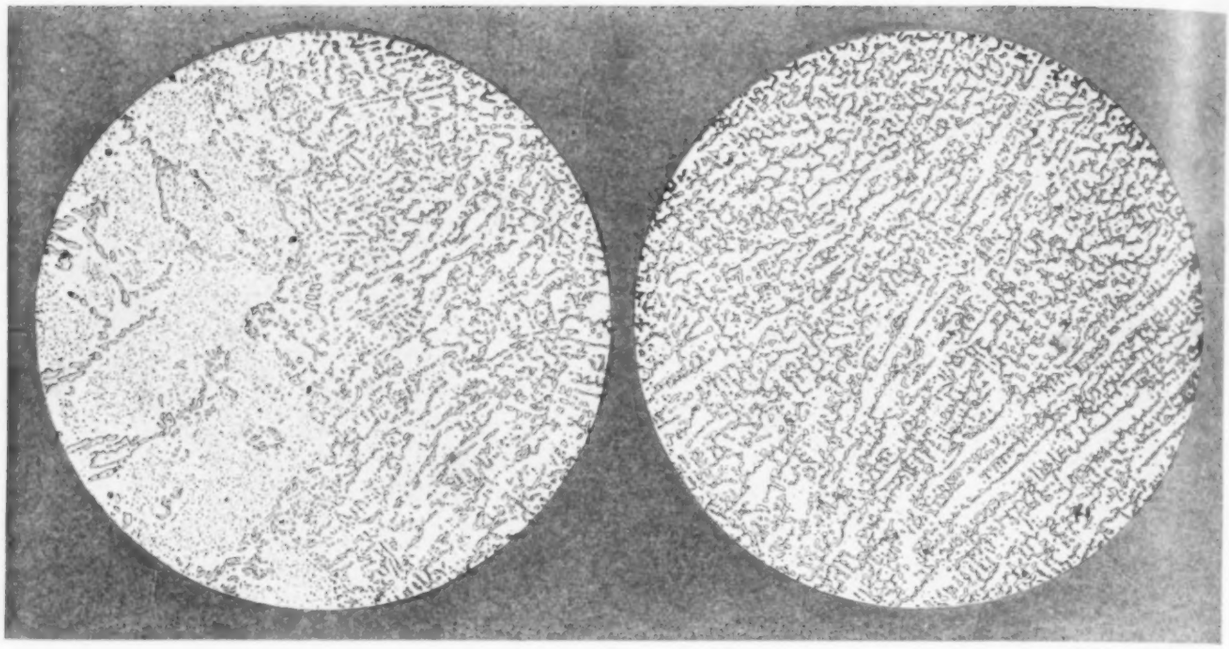
amination of the X-ray film whether a satisfactory weld can be made, and can check his findings by a re-take of the repaired area.

Repair welds are necessary, in spite of good foundry practice, because of certain physical characteristics of high nickel-chromium alloys. The extreme sluggishness of the molten metal, and its high rate of shrinkage from the liquid, present severe difficulties to the foundryman. The high cost of the castings in the mold means that the scrapping of them is a much more serious matter than it is in an iron or steel foundry. With the knowledge that perfect welds *can* be made under proper conditions, therefore, the alloy founder is justified in spending considerable time and money to perfect the welding technique.

In addition to the stability of welded repairs on alloy castings, proven by ample evidence of castings in severe service, it has been demonstrated that major welds joining together several castings give satisfactory service under carburizing conditions, which are among the most severe of alloy applications. The company with which the writers are connected fabricated a tubular structure 20 ft. long, consisting of six castings joined with 42 ft. of welded seam, which has recently been removed from service after a life in excess of that given by another mechanically joined assembly of castings of the same alloy in the same furnace. A similar installation, comprising nine castings joined with 65 ft. of welded seam, and 30 ft. in length, is now in operation. The wisdom of installing such structures would be open to question, however, unless the welds (as well as the individual castings) were subject to X-ray inspection, since the high cost of fabrication must be justified by continuous, trouble-free operation for a long period of time.

Objections to Large Units

Some engineers object to the installation of such large units, because they fear that satisfactory repairs could not be made if the unit should be damaged after exposure to a carburizing atmosphere for a period shorter than the normal life. Such damage might consist of a crack caused by too rapid heating after a shutdown, or in some other injury resulting from the failure of some of the heat controls. This would necessitate replacing the entire alloy unit, provided a satisfactory repair of the injured part could not be made. Many metallurgists feel that the changes which occur in nickel-chromium alloys, after exposure to a carburizing atmosphere for a long period of time, are of such nature that their properties differ radically from the original metal. In such case, it might be impossible to obtain a good weld on carburized material or to insert a piece of virgin



Micros at 100X of Welded Spot in Carburizing Box After 8500 Hr. Service. Left, transition zone from casting to weld; right, center of welded seam

alloy to effect a major repair and save the unit.

The two micros at the head of this article illustrate what is probably the only major change which takes place in high alloy castings under normal carburizing conditions — namely, in the quantity, size, shape and distribution of the carbide constituent. They represent a carburizing container of the 65% Ni, 15% Cr analysis, which had been in commercial service for 8500 hr., with natural gas as the carburizing medium. It is quite evident that there has been some penetration of carbon and this extended about $\frac{1}{16}$ in. deep. Chemical analysis showed the carbon content of the outside skin (lower view) to be 0.56%, while that of the inside (upper view) was 1.53%. Since the carbon penetration is very slight it will have little effect upon welding, even though there might be any difficulty in welding low and high carbon alloys of this type — which in fact there is not.

X-ray diffraction patterns were taken of the areas covered by the photomicrographs, in an effort to determine possible changes in grain size, which the authors have found impossible of accomplishment by ordinary metallographic means. While it is not possible to differentiate grain size closely even in this manner, we can say that there is no great difference at any point in the section. Grain growth is usually innocuous except for its embrittling action (and this casting after long use certainly was not brittle) and its tendency to promote intergranular corrosion. Since any intercrystalline corrosion would doubtless show in the etched specimens under the microscope, there is therefore no apparent reason why successful welds cannot be made even after this long period of service.

Proof of this statement is given by the photo on page 196 (slightly enlarged) of a weld joining a piece of cast 65% Ni, 15% Cr alloy which has not been in service, and a piece of the same alloy taken from a scrapped carburizing container which had given normal life in commercial operation. The welding rod was a low carbon rolled alloy of the same nickel and chromium content as the casting, and ordinary shop practice was used in making the weld. The polished and etched piece shows a good joint, with no defects aside from the shrinkage in the center of the older fragment — known to be present because it was plainly shown on the radiograph of this part of the original casting taken before shipment and before a long life of usefulness. The five views on pages 196 and 197 show the microstructure of the weld itself, the junctions with the old and

(Continued on page 200)

Corrosion-Resisting MATERIALS OF CONSTRUCTION

DURIRON

Physical Characteristics

Weight, lbs/cu/in	.255
Melting Point, degrees F.	2300
Electrical Resistivity, Microhms per Cm³, O°C	63
Thermal Conductivity (Ag-1) O°C	0.125
Scleroscope Hardness	50
Tensile Strength (½" diameter bar)	16,000 lbs.
Coefficient of Expansion, degrees Fahr.	
32-212	0.00000360
32-932	0.00000775
32-2300	0.00001560

Machinable only by grinding, due to extreme hardness.
Weldable with oxyacetylene flame.

Corrosion Resistance

Duriron is outstanding among chemical corrosion resisting materials, not only because of its extremely high resistance to practically all chemical solutions, but also due to its extreme hardness.

The resistance of Duriron to corrosion and abrasion makes it ideal for acid solutions carrying solids in suspension, such as slurries, rouge liquors and similar solutions.

Duriron is of special value to the chemical engineer in that the same equipment can be used for his whole range of corrosives, thus reducing the amount of equipment and parts necessary. Send for Bul. No. 150.

Equipment Available

Centrifugal Pumps
standard
self-priming
Measuring pumps
Y valves, Gate valves,
Plug cocks, Lubricated cocks, Foot valves,
Check valves, "Plunger-Release" plug cocks, Pipe and Fittings
Steam jets
Exhaust fans
Kettles
Ejectors
Condensers
Heat Exchangers
Mixing Nozzles
Special castings made to order

DURI-CHLOR

The physical properties of Durichlor are practically the same as those of Duriron, including machining and welding.

Durichlor is almost entirely resistant to Hydrochloric Acid in all strengths and at all temperatures up to the boiling point. Handles other acids as well. Bulletin No. 400 gives complete data—send for it.

Standard equipment as listed above, as well as special equipment, is available in Durichlor.

DURIMET

C — 0.07%
Ni — 22%
Cr — 18%
Varying percentages of Mo, Si and Cu

Weight, lbs/cu/in	.282
Specific heat	.118
Casting shrinkage per ft	5/16"
Electrical resistivity	96.62
Melting point	2650°F.
Structure	austenitic
Coefficient of Expansion	
20-100°C	0.000014
20-1000°C	0.000020
Ultimate strength	68-72,000
Hardness—Brinell	130

Durimet is especially recommended for weak sulphuric acid under the most severe conditions. Also satisfactory with dry chlorine, copper sulphate, ferric sulphate, nitric acid, crude phosphoric acid, silver nitrate, sodium hydroxide, sodium sulphite, sulphurous acid, sulphite liquors, hot or cold. Bulletin No. 171 has a more complete list—send for it.

The equipment listed above is made also in Durimet, except pipe. In addition, there is much special equipment produced, such as autoclaves, special high pressure pumps, special valves, pickling racks and baskets, and parts subject to severe corrosion. You are invited to send your drawings for estimates in Durimet or any of the other corrosion-resisting alloys, without obligation, of course.

DURCO

KA 2S
KA 2S Mo
C — 0.07%
Cr — 18%
Ni — 8%
Mo — 3%

Weight, lbs/cu/in	.284
Specific heat	.120
Casting shrinkage per ft	5/16"
Melting point	2650°F.
Structure	austenitic
Coefficient of Expansion	
20-100°C	0.000019
20-1000°C	0.000022
Ultimate strength	80-95,000

Acetic acid, glacial, hot or cold; carbolic acid, dry chlorine, fruit juices, nitric acid, crude phosphoric acid, sodium chloride, sodium sulphate, sodium sulphite, sulphurous acid gas, calcium and sodium bi-sulphite, vinegar. See Bulletin No. 171 for more complete data.

Centrifugal pumps from 1" suction, 1" discharge to 8" suction, 6" discharge; Y valves, gate valves, lubricated valves, globe valves; elbows, tees, crosses, unions, plugs, caps and couplings; Panzl strainers, other standard equipment and special castings made to order.

ALCUMITE

Copper base aluminum alloy

Weight, lbs/cu/in	.273
Casting shrinkage per ft	3/16"
Coeff. of Expansion, degree F.	0.00000935
Tensile strength	
Green sand castings	65-70,000
Hot rolled rod	85-100,000

Sulphuric acid under non-oxidizing conditions, hydrobromic acid, weak hydrofluoric acid, hydrofluosilicic acid, nickel sulphate, sodium hydroxide, many organic acids, animal and vegetable oils and sludge acids. Bulletin No. 701 sent upon request.

Centrifugal pumps, valves and similar equipment, as well as bars, tie rods, bolts, nuts, and washers. Special equipment made to order.

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In our experience of over 50 years devoted to wire work, we have developed skilled artisans able to turn out fine wire on a production basis and do it economically and with surprising uniformity.

Wire held within close tolerances, drawn in our own mill under strict supervision of experts leads us to ask you to think of us as specialists in this field, when you are next in the market.

THE
C. O. JELLIFF MFG. CORP.
SOUTHPORT, CONN.

JELLIFF EXHIBIT BOOTH N-11

Welded Pots

(Continued from page 198)

new cast pieces, and the metal adjacent to the junctions on either side. (Note that the weld metal in one view was badly scratched and pitted during preparation of the sample; it really has a structure like the central view.)

That welded foundry defects stand up in service is shown by the last two figures on page 198. A defective area was discovered by X-ray before shipment of the carburizing container previously described, and removed and welded, using a cast rod of approximately the same composition as the casting. The left view is the junction of the weld with the casting and the right view is the weld metal after 8500 hr. service. The more even distribution of the carbides in the weld metal, and their more uniform size, can be accounted for by the rapid rate of cooling of the molten weld metal as compared to the cooling rate of the molten metal in the original casting.

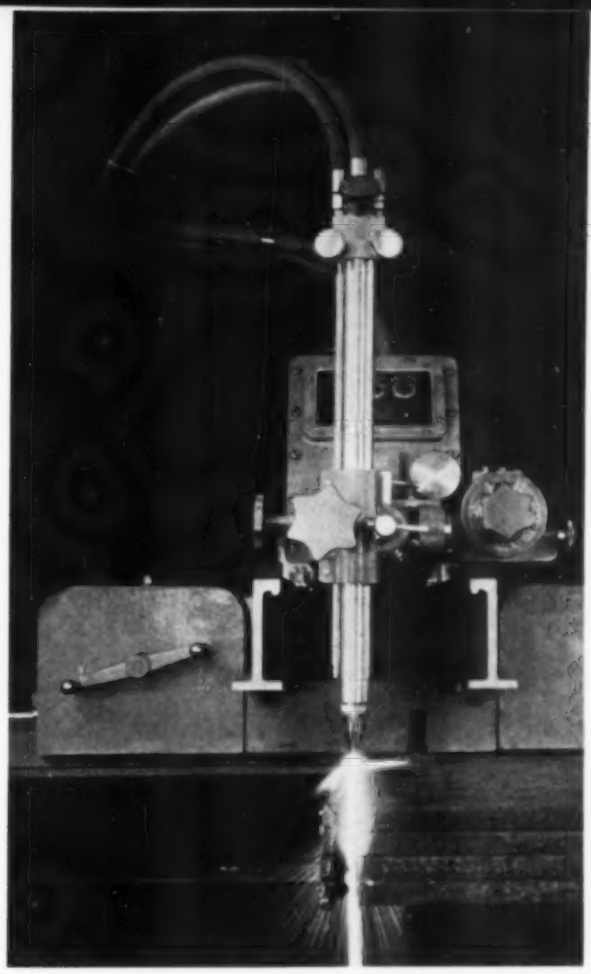
The technique of welding alloy castings is radically different from that involved in welding steel or other metals. Polarity must be reversed in arc welding, small beads laid down with frequent peening, and puddling must be avoided. Extra precautions must be taken to avoid cracking, on account of the physical characteristics of the alloy. It is inadvisable to allow welds to be made, therefore, except by men accustomed to the work. Even expert operators on steel have great difficulty when first trying the high nickel-chromium alloys. Increased use of the X-ray in examining welds for physical defects is also to be expected. Not only does such examination assure a sound weld, but its continued use increases tremendously the quality of a conscientious welder's work.

WELDING

and

CUTTING

OF METALS



Modern Cutting Machine Trimming Ends of Four Plates, Stacked

RECENT PROGRESS in the welding and cutting of metals is largely a direct result of the increased attention given to the metallurgical aspects of these processes. This is as it should be, for they are definitely metallurgical in character.

In fusion welding, for example, a whole range of physical changes occurs simultaneously or in rapid succession in a limited area — a phenomenon that is almost without parallel in other metallurgical work.

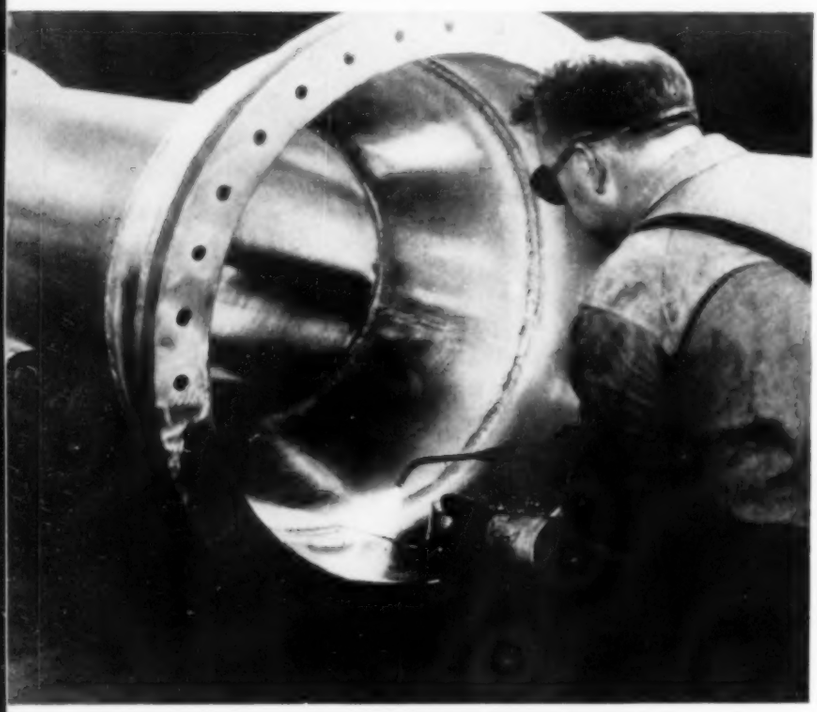
In the reduction of ores, refining of metal and its subsequent treatment in the mills, the various operations are usually conducted as separate steps. The metals are smelted and refined under conditions which exclude contact with the atmosphere and which permit careful control of chemical and physical characteristics through the addition of cleansing agents and, if required, alloying elements. The change from molten to solid state takes place as a separate operation and the solidification conditions are such that the molten metal has little or no effect on the confining medium. Subsequently the metal may be heat treated to improve its physical properties. The effects of expansion and contraction are seldom encountered until the metal has been fabricated and placed in service.

Metallurgy of Welding

In making a fusion weld, however, all of these different effects may occur at one time, concentrated in a relatively small area. By the heat of the flame or arc, a localized spot in a body of cold metal is suddenly brought to the molten state. The confining medium surrounding the molten puddle — instead of being an extraneous body as is the case in making a casting or an ingot — is part of the finished structure. Consequently a temperature gradient exists in the weld and surrounding base metal, extending all the way from the fusion point, or somewhat above, to room temperature. Certain areas in the base metal are therefore subjected to conditions similar to those produced in heat treatment. Frequently the molten metal may be exposed to the atmosphere and the chemical reactions which result from such contact must be taken into account. When the weld metal cools, the almost irresistible effects of contraction are encountered and complicate the

expansion effects produced during the initial heating.

From even this somewhat sketchy outline, it is at once evident why metallurgists are interested in welding as a metallurgical process and why increased attention to the metallurgical aspects has played such an important part in recent progress in welding. Flame cutting also involves metallurgical considerations and has progressed in proportion to the study given to these factors.



Chemical Plant Leans Heavily on Oxy-Acetylene for Fabricating Its Equipment. This is the shell of a heat exchanger made of aluminum. Courtesy Linde Air Products Co.

In addition — and this is really the more important consideration — the metallurgist is deeply concerned with the practical applications of welding and cutting as methods of joining and severing the metals he produces. Welding has become so widely accepted as an ideal joining method in the fabrication of metal products, that, in the development of new metals and alloys, weldability ranks high with other physical properties in determining their scope of commercial application.

Similarly, modern methods for the fabrication of a constantly increasing range of metal products are dependent upon, and indeed would be almost impossible without, the use of flame cutting.

For these reasons, the American Society for Metals is paying particular attention to keeping its members constantly informed with regard to current developments in welding and cutting processes. This is evidenced by the number of articles on these subjects that have appeared in METAL PROGRESS, and particularly by the greatly extended treatment given these subjects in the new edition of the Metals Handbook. These last mentioned articles were prepared under the sponsorship of the International Acetylene Association, which appointed a special committee to handle the work. The International Acetylene Association felt that in order to do full justice to the subject, three electric welding experts should join the committee. The full membership was therefore as follows: C. W. Obert, Chairman, E. V. David, L. B. Meeker, S. C. Osborn, E. W. P. Smith, and A. G. Wikoff. (This review utilizes the handbook information as well as the recent articles in other publications.)

The sections on welding and cutting in the 1936 Metals Handbook have therefore been designed to give fundamental data regarding the various processes and their applicability in joining and severing the numerous metals in commercial use. As the actual work of welding or cutting will, in practically every instance, be handled by a trained operator, the metallurgist and engineer are frequently not concerned with the details of operating technique, and accordingly this phase of the subject has been treated only very briefly.

The information given regarding the various processes is of such character as will enable the metallurgist to determine in general the practicability of a specific welding or cutting operation. The importance of such data is evident from the range of welding methods which the modern fabricator of metal has at his disposal. These include forge, resistance and thermit pressure welding, in addition to the fusion welding methods such as gas, metallic arc, carbon arc, atomic hydrogen and thermit. Similarly, flame cutting has developed to the point where there are a number of ramifications that should be thoroughly understood by those interested in applications of the process.

Fusion Welding

Fusion welding may be defined as a localized union or consolidation of metals, usually employed to unite like metals for purposes

where the union or joint will be called upon to develop strength and transmit stress. Three outstanding characteristics of all fusion welding processes are: (1) The consolidation is localized; (2) the metal in the joint must be heated above its thermal critical point; and (3) the weld is accomplished in a comparatively short time and usually in a progressive manner. Thus it can be seen that these processes involve metals under the effect of heat and therefore are subject to the same thermal, chemical, physical and metallurgical manipulation that is commonly known in the manufacture and heat treatment of metals.

The scientific consideration of welding has resulted in a horizontal advance of the various processes. Study of the fundamentals has not only resulted in improvements in these processes but has established the types of work which each method is best equipped to accomplish. During the past few years a vast amount of valuable data has been obtained regarding the welding characteristics of metals and accurate conclusions have been determined for the majority of the most frequently used materials. These studies reveal the reactions of each type of metal to each welding process and information is available as to the correct technique to be employed, the filler materials to be used and the manner and degree of any special treatment.

Fire-Eating Monsters in Their Cage, but Arc Welders Assisting Reinforcement for 16-Ft. Concrete Pipe (Aqueduct From Colorado River to Los Angeles). Courtesy Lincoln Electric Co.

Stress Relieving

An interesting subject which has developed from the fundamental studies of fusion welding is the matter of stress relieving. Old-time boiler makers knew that varying degrees of localized stress were set up in areas adjacent to the flanged edges or bends in members fabricated by localized heat. Welding intensifies this trouble. The number of welds, their position and the welding technique employed all influenced the magnitude of these stresses, and it was found that they could be entirely relieved (or at least rendered innocuous) by utilization of suitable heat treatment. This type of heat treatment has become known as "stress relieving." It involves heating the welded part or assembly uniformly to a temperature between 1100 and 1200° F., at which temperature it is held for one hour for each inch of thickness of the thickest part welded; cooling is then allowed to occur slowly until about 200° F. is reached.

The American Society of Mechanical Engineers has included a section on the stress relief of welded structures in its code governing the construction of unfired pressure vessels. This code specifies what structures must be stress relieved, what degree of heat treatment is to be applied and which of several stress relieving methods shall be utilized.

Bronze Welding

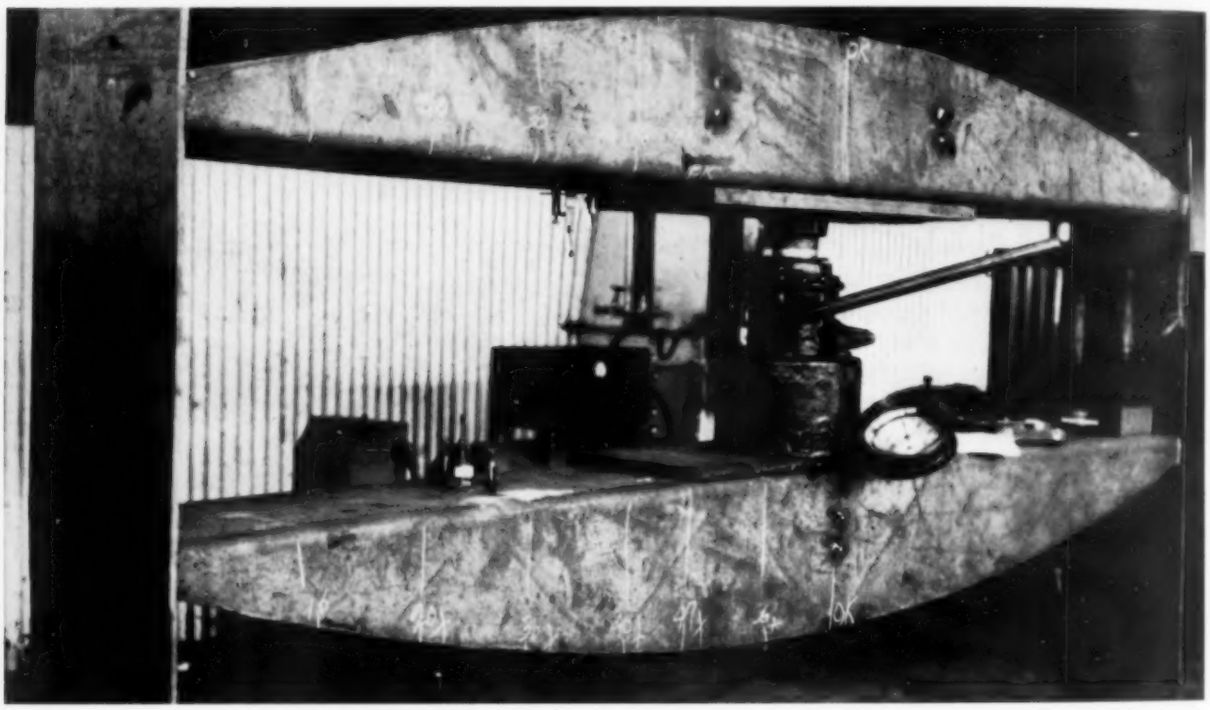
A welding method which has become of extreme value in recent years is known as "bronze welding." This is not a true *fusion* welding process, as the metal parts to be welded are not actually melted but only heated to a point where "tinning" and amalgamation with the added bronze takes place. A highly satisfactory bond for many types of work is obtained in this manner; oftentimes, as with cast iron, the joint between metal and bronze filler is stronger than the base metal itself. Recently investigations into the character of this bond have revealed that adherence of bronze to the base metal is a result of three effects — tinning, alloying and intergranular penetration. The relatively low temperature required for bronze welding is responsible for greatly increased working speeds, and the property of bronze to yield readily as it cools reduces the possibility of locked up stresses in welded castings. Intergranular penetration must be borne in mind when bronze welding susceptible metals, subject to shock in service.

Hard Facing

A number of materials, certain of which were developed primarily for use as cutting tools, have been found to be exceptionally resistant to wear and abrasion. By means of a welding method known as hard facing, the usefulness of these materials has been extended economically into many fields where the wear and abrasion of metal parts are encountered. In hard facing, a relatively thin layer of one of these materials resistant to wear is welded on the exposed surface. This is readily done either with electric arc or gas welding processes; most of the common metals of construction can be successfully hard faced.

There are many varying uses for hard facing materials, and for this reason they are available in a wide number of different compositions. Type 1 consists of extremely cheap and short lived alloys such as plain carbon steel. Type 2 is made up of alloys of an iron base with chromium, tungsten, manganese, silicon and carbon. These are relatively inexpensive and fairly resistant to wear; they are used principally for building up large volumes in badly worn parts. Type 3 consists of true hard facing alloys having compositions ranging from 50 to 80% iron with additions of one or more of the alloying elements used in Type 2 and sometimes small amounts of cobalt or nickel. Type 4 also consists of true hard facing materials and is principally non-ferrous alloys of cobalt, chromium and tungsten. Type 5 consists of the carbide materials composed mostly of tungsten carbide particles with small percentages of ductile metals for binder. These are furnished in the form of small castings which are welded onto wearing surfaces by means of still another metal; this is called "hard setting" and results in an extremely wear resistant surface. Type 6 includes crushed tungsten carbide fragments, made available for welding by being packed into a mild steel tubular sheath, being fused to a strip of metal, or combined with other hard facing alloys in welding rod. This is the longest lived type of hard facing material.

The ability of hard facing to protect the surfaces receiving the greatest amount of wear permits the utilization of cheaper metal for the rest of the machine or part. Hard facing keeps wearing parts in efficient condition longer, thus decreasing the amount of power required and the number of shutdowns for replacement.



Economical Design for Welding Cannot Merely Replace Castings or Articulated Members, Section by Section, but (in Complicated Assemblies) Requires Photo elastic Studies of Transparent Models and Physical Tests on Completed Weldings (Either Full or Fractional Size). Photo is of a static test on experimental crane girder at Lukenweld Inc.

Inspection, Testing, Codes and Specifications

As the art of welding has progressed methods for testing and inspecting welds have naturally been developed because, to determine many of the characteristics of a weld, it has been necessary to depart from the usual methods of metal examinations. As a consequence several of the commonly used methods of testing welds are unique.

Testing methods are of two general types, destructive and non-destructive. For the establishment of quantitative information, destructive tests are necessary. For an indication of quality, the non-destructive methods can be used. The tensile test (a destructive test) is one of the most frequently used, as it reveals the tensile strength, yield point, elongation and reduction of area of the composite at the weld (or the base metal, if the weld is stronger and stiffer). The bend test, another destructive method, is a very excellent method for determining the ductility of the weld. Variations of this last test known as the "root break" and the "side break" test reveal lack of penetration and side wall fusion.

The specific gravity is frequently determined to insure freedom from fine porosity at the joint. The nick-break test indicates whether complete penetration has been obtained, whether any oxides are present and what degree of porosity is in the weld metal. Impact and hardness values can be determined with the usual machines. The stethoscope may be used for non-destructive investigation, revealing by means of sound much information as to the integrity of the joint.

X-ray and gamma ray tests are widely used non-destructive tests which record on photographic plates any inner defects at the joint.

Electric resistance and magnetic tests which have been recently developed are finding successful use in many instances as non-destructive methods of examination. For testing the tightness of pressure vessels and closed containers the hydrostatic proof test is often used.

Taken as a whole these tests, combined with adequate supervision during the work, and visual examination of the completed job, offer adequate means for the investigation of welds and the assurance of safety. Their use also is invaluable in the determination of correct welding procedures.

During recent years code-making organizations have included the fusion welding processes as acceptable for the fabrication of most structures which for reasons of safety are usually manufactured under regulations. Many construction projects accept fusion welding in their specifications and a considerable number go so far as to specify the safety requirements insofar as they apply to manner in which welding shall be executed and the results which will be expected in the final tests.

Final Inspection Under Magnifying Glass of Welds in Alloy Steel Tubing Making up Large Spars for Airplane Wings. Photo by Hine

The recognition of fusion welding by regulatory bodies has given great impetus to the advance of the process in encouraging its development for use as a production method. Among the more important codes and specifications including applications of fusion welding are: the A.S.M.E. Boiler Construction Code; the A.P.I.-A.S.M.E. Unfired Pressure Vessel Code; The Marine Boiler Construction Rules of the U. S. Bureau of Navigation and Steamboat Inspection; Rules of the Bureau of Engineering, U. S. Navy Department; National Board Rules for Repair of Boilers by Fusion Welding; A.S.A. Pressure Piping Code; the Manual of the Heating and Piping Contractors National Association; numerous rules prepared by the American Welding Society and the International Acety-

lene Association covering specialized applications requested by other industrial groups. Extracts covering the important features of each of these codes are contained in the new ⊜ Metals Handbook.

Gas Cutting

Gas cutting has grown within a few years from a tool for the performance of crude cutting operations to a highly developed process with practically unlimited scope. It is available to industry today for countless applications in the fabrication, shaping and finishing of ferrous materials. This growth has come about partly as the natural development of a process which conveniently and economically fitted into the metal working art and partly through process and equipment improvements which carried along with the normal development of the industry itself. The introduction of the mechanically operated blowpipe and then the automatic cutting machines (such as illustrated at the head of this article) permitted the process to keep pace with the trends of large scale production and to meet the demands for greater accuracy.

The most recent developments in gas cutting — developments which give a glimpse of the immense possibilities within its future scope — have come about from another consideration, namely, the realization of its metallurgical aspects. One had only to try to cut high carbon and alloy steels to realize that many of these materials did not yield the usual satisfactory results when cut with a flame. Then it was that the process was recognized to have a metallurgical relationship to the products with which it was used. Then ensued a period of extensive research into fundamentals. Through these investigations the reactions of various materials to gas cutting have been observed and today the fabricator has at his disposal data on how to cut the metal at hand, as well as on how to produce a complicated shape.

For example, considerable information is already available regarding the effect of gas cutting on steels. Metal adjacent to the cut surface is heated well above its critical range and of course cooled again through this range, and the cut surface is considerably changed from its original condition. The change, which is physical and not chemical, involves either the refining of the pearlite in the original annealed material or the transformation of pearlitic steel into one or the other of the unstable microstructures, martensite or sorbite. The rate of cooling together with the alloying elements present determine the resulting structure. It will also be observed that there is an appreciable grain growth at the cut edge.

In gas cutting steels containing not over 0.35% carbon, the semi-hard sorbitic structure is produced at the very surface layers. In general, this is more desirable than the original pearlitic structure, being stronger and tougher; thus these steels rather than being damaged are if anything improved. If edges which have been gas cut are subsequently welded they revert to their original pearlitic state as a result of the annealing effect of the welding operation. Recent investigations by the A.S.M.E. Boiler Code Committee have substantiated these results and consequently all restrictions in the Boiler Code as to the welding of surfaces prepared by flame cutting steel containing not over 0.35% carbon have been removed. Further tests at Massachusetts Institute of Technology and elsewhere have recently shown that the physical properties of flame cut edges of mild steel are considerably more desirable than those of sheared or friction sawed edges.

When higher carbon and alloy steels, particularly if at room temperature, are flame cut the resultant surface structure may be hard martensite. This structure, being extremely hard and brittle, is very liable to crack while cooling. It has been found, however, that by preheating these steels to 500 or 600° F. before cutting, no cracks occur on the cut surfaces. The newer, low alloy, structural steels should also be preheated before flame cutting, and in general it is found advisable to preheat and anneal the higher carbon and alloy steels such as the S.A.E. steels.

Flame Cutting Techniques

Most of the commercially used ferrous metals can be cut. However, the characteristics of many of them require special handling. As a consequence several different flame cutting techniques have been developed. The 1936 ⊜ handbook contains a chart wherein common metals and alloys are listed with the technique recommended for cutting.

Flame cutting techniques are classed as five distinct types. Type No. 1 flame cutting is that universally used with ferrous metals such as the low carbon steels which can be readily cut.

Back and Rear Quarters of All-Steel Body Are Welded Into a "Balloon" in a Cascade of Sparks. This enormous resistance welder (one of two) completes two long seams simultaneously. Courtesy Ford Motor Co.

This technique requires no special manipulation of the blowpipe, as the cut progresses freely at the will of the operator. Accurate control of the blowpipe is possible, as the high velocity of the oxygen stream holds it to a narrow path and permits close control of the oxidizing action.

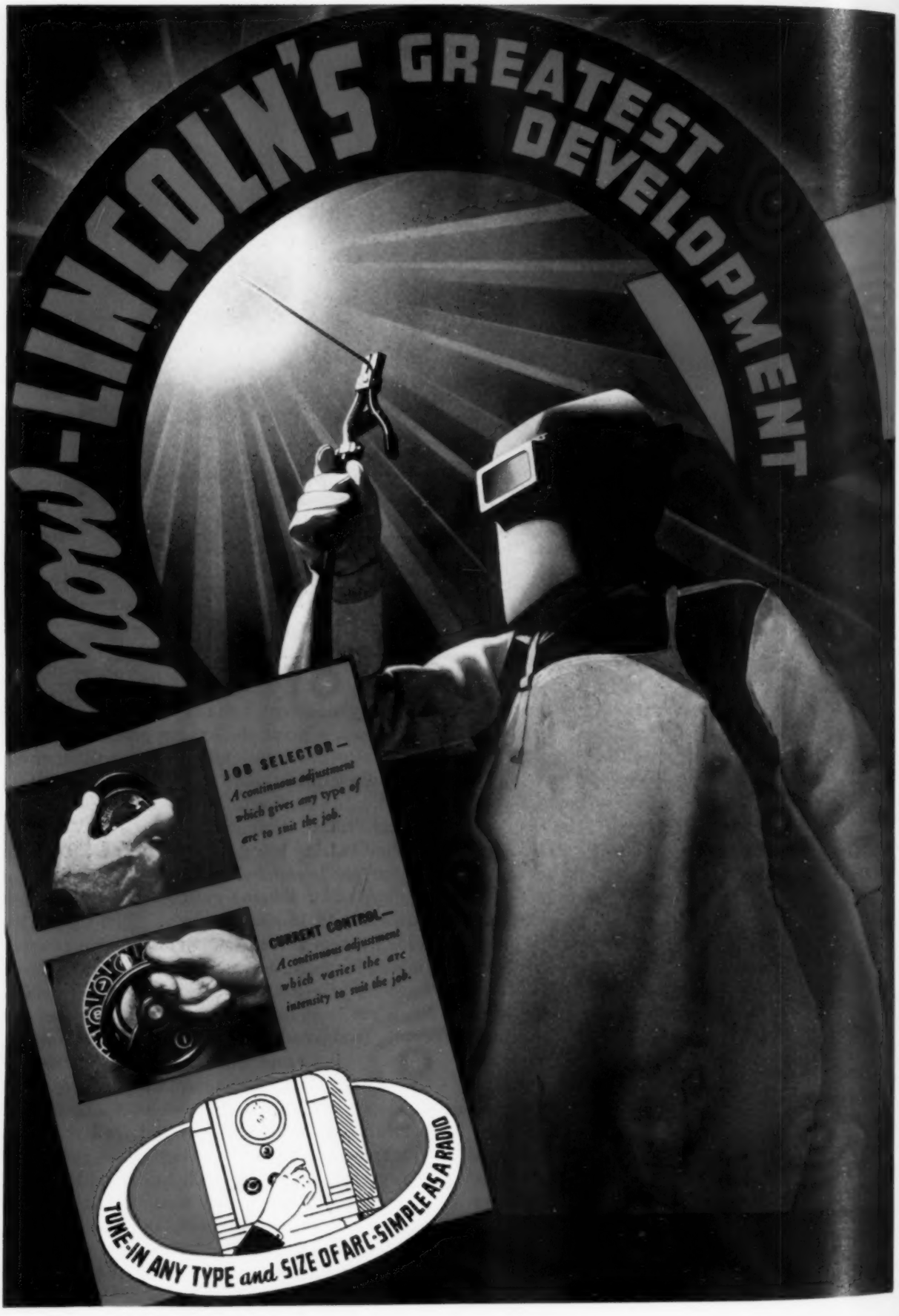
Type No. 2 flame cutting is familiarly known as "oxygen lance cutting." This technique can be used for piercing most of the ferrous metals and it is particularly valuable for cutting heavy sections of metal. The procedure consists in burning *with oxygen alone* metal which has previously been brought to a kindling temperature. The oxygen is brought to the point of work through a length of iron pipe, the lance, which is consumed as the cutting progresses. Type No. 2 flame cutting is seldom used alone as a production process but often in conjunction with Type No. 1 in the cutting of heavy sections. It is used independently, however, for many specialized applications such as opening furnace tap holes, and piercing holes in salamanders, ladle chills and huge masses of iron or steel.

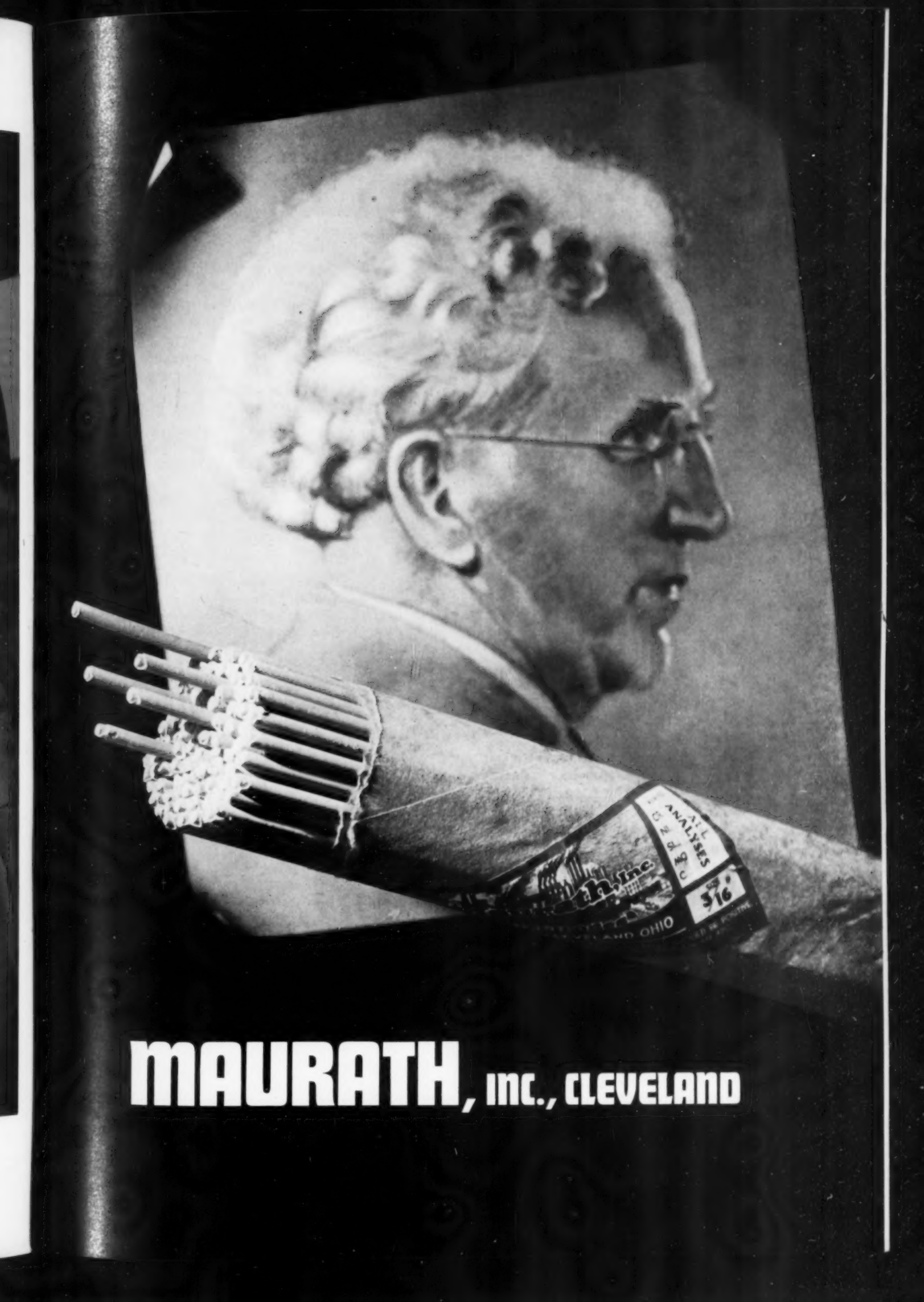
Type No. 3 flame cutting is the procedure especially developed for cast iron. It is considerably different from Type No. 1. In the first place, a great deal more preheat must be used to start and maintain the cut, and secondly a definite flame oscillation is necessary in a sidewise motion in the form of half circles. As a result of these variations the costs of Type No. 3 flame cutting are greater than for No. 1 and the surface is somewhat rougher.

Type No. 4 flame cutting is the technique used with the stainless steels. This procedure also involves the use of an oscillating motion. In this instance, however, it is in the form of short backward and forward strokes. In starting a cut in stainless steel the whole line of the cut is preheated rather than just the starting point. It is also of extreme importance in cutting stainless steel to maintain a steady flow of slag. Although successful cuts are readily obtained the resulting surface is rather rough.

Type No. 5 flame cutting is the procedure for severing metals difficult to cut, with the aid of metals that are easily cut. This is accomplished by covering the metals of low cutability with metals of high cutability so as to initiate the cut under good conditions. The presence of

(Continued on page 226)


NOW-LINCOLN'S GREATEST DEVELOPMENT
JOB SELECTOR—
A continuous adjustment which gives any type of arc to suit the job.
CURRENT CONTROL—
A continuous adjustment which varies the arc intensity to suit the job.
TUNE-IN ANY TYPE and SIZE OF ARC-SIMPLE AS A RADIO



MAURATH, INC., CLEVELAND

Gas Cutting

(Continued from page 221)

a bar of low carbon steel at the point of cut or the use of iron filings is another variation of this technique. Type No. 5 flame cutting can be used to assist any of the other four procedures.

Applications of Specialized Cutting

Many variations of flame cutting have evolved from the original simple blowpipe. Of course manual cutting is still widely used throughout industry and will continue to be invaluable for many applications, especially in repair and emergency. However, the trend toward machine flame cutting has offered the most radical and important advances in production, and has led the process into several fields of metal working which were beyond consideration a few years ago.

As has been stated before, flame cutting machines of today are capable of producing, automatically, accurate cuts ranging from a simple straight line to the most complicated shapes. Materials of almost any thickness or size can be handled. Most of the machines are motor driven and are equipped to follow a templet or respond to the manual guidance of a tracing device.

Precision machine cutting is possible by utilizing correct technique and closely adjusting pressures and speeds. Surfaces in 1-in. plate true to 0.003 in. as to cross sectional squareness have been obtained. Many special types of work can also be successfully done: Pieces which are not flat can be successfully cut; cuts can be made in different planes, levels or angles on the same piece; sections of variable thickness can be cut; I-beams and other structural members can be severed. For the production of large numbers of identical shapes, several plates may be stacked together, accurately lined up and all cut at once. Another provision for production cutting is multiple cutting, where from two to six blowpipes operate simultaneously on one guiding machine, following the same design.

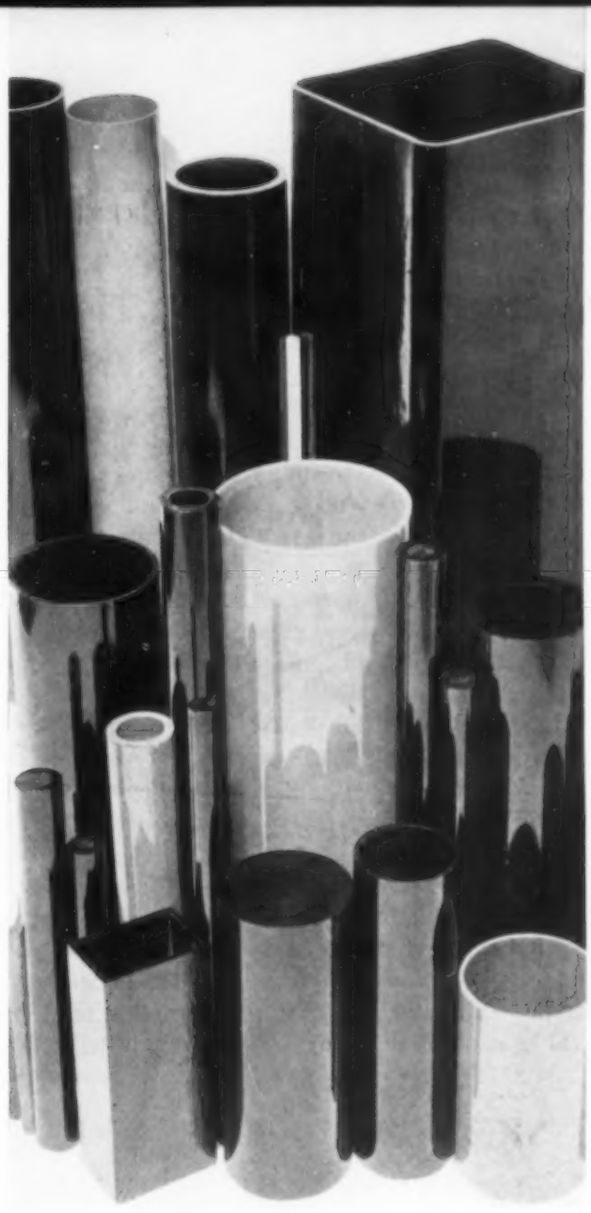
Another phase of gas cutting which is newer and holds tremendous possibilities is *flame machining*. In this type of cutting the metal part is not completely severed but a predetermined depth and width is removed from the surface. This effect is obtained by impinging the cutting oxygen jet on the surface at an acute angle. (See METAL PROGRESS, May 1936.)

Flame machining operations which are at present being successfully employed are: planing, drilling and boring, (flame planing includes the deseaming or gouging of billets or castings for removing cracks, seams or other defects); hogging, or the removal of superfluous metal from castings; surface planing, which is a refinement of deseaming in which cuts are made adjacent to one another, thus permitting a wider surface to be removed. Flame drilling or punching is developing rapidly as a valuable application; it is possible to produce accurate, uniform, straight sided holes. Rough boring with the flame is also accomplished quite successfully and seems to offer a future field of some extent.

The applications for gas cutting extend into all the phases of metal working and they all offer possibilities of greatly increased utility. This will come about through the establishment of the metallurgical relationship between gas cutting and the new materials, and of new requirements as they develop.

Cutting Blowpipe, Operated by Skilled Workman, Is Universally Used on Structural Steel Work — in the Fabricating Shop, for Minor Corrections During Erection, for Repairs and Renewals, and for Dismantling

Activity in Copper *and* Light Metals



Editorial Review

IN A NOTABLE REVIEW of the future status of non-ferrous metals appearing in January 1935, Zay Jeffries, Past President ⊕, looked forward to bright days, listing the following favorable factors in the relatively near future:

1. It is certain that the engineering suitability of non-ferrous metals will be in much greater proportion to iron than the present ratio of consumption, and engineering suitability will be given a greater weight as compared with cost.
2. Elapsed time is in favor of non-ferrous metals receiving more than their former share of metal consumption.
3. The Western World should not have reached its peak either in metal consumption per capita, or in population.
4. Any increase in metal consumption in the backward countries of Asia and Africa will be exceptionally favorable to non-ferrous metals.

As to the longer view ahead, he also had these points to make:

1. The time cannot be visualized when any metal will even be a close second to iron, from the tonnage standpoint. (At present the world pig iron production is 14 times that of all non-ferrous metals combined.)
2. New non-ferrous metal production should increase in comparison with new iron production, at least for several generations.
3. Aluminum will eventually be the largest tonnage non-ferrous metal. (It is now surpassed only by copper, zinc and lead.)
4. The time cannot be visualized when any of the major non-ferrous metals will be so far exhausted as to rob industry of the richness in variety and combinations of properties which they make possible.

Aluminum

Turning now to the light metals, it may be said generally that each of our commercial metals has gained its present position because it meets certain requirements more economically than any other material, or because its use provides some special satisfaction to human

beings. Aluminum on this basis owes its rapid development to its resistance to atmospheric and many kinds of chemical corrosion, its low weight, its ability to be hardened and strengthened by alloying and heat treating, its easy workability and its heat conductivity.

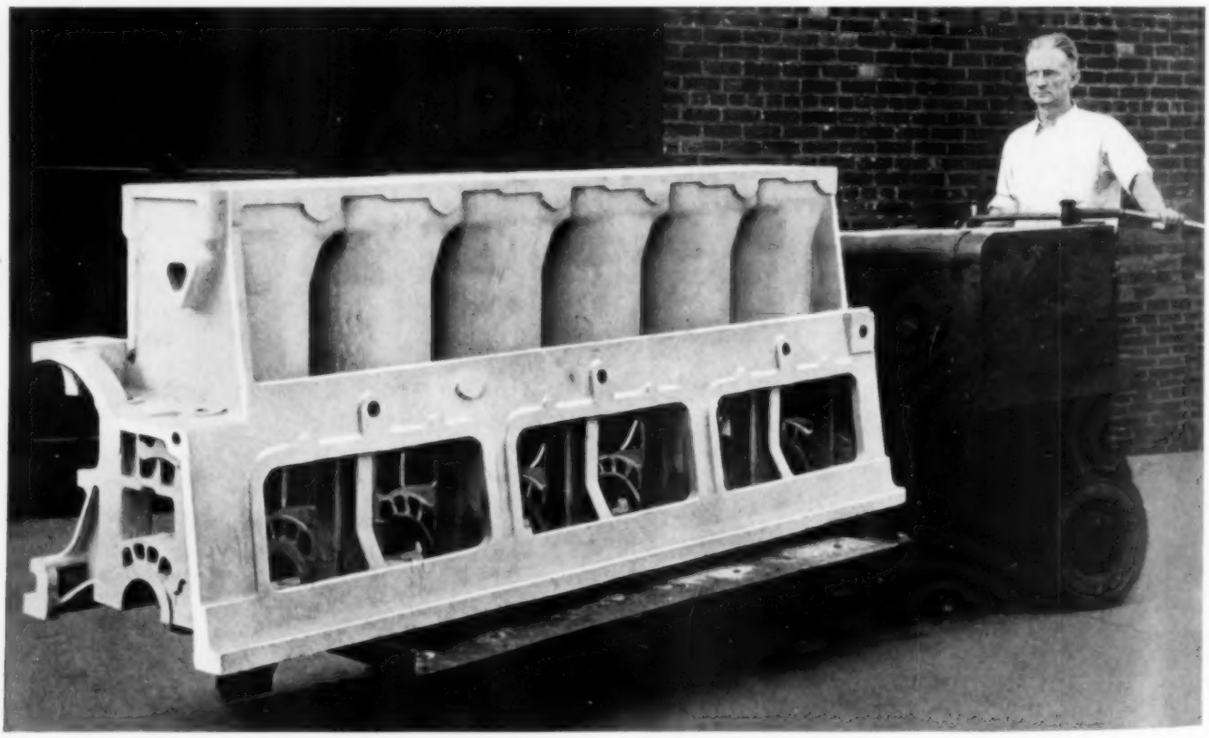
Many, if not most, of the engineering applications of aluminum are based on the fact that, using it, a strong member can be light. Expressed technically, it has a favorable strength-weight factor. This matter is of obvious importance to the aircraft industry; J. B. Johnson ⊜ presented a table in METAL PROGRESS just a year ago showing that whereas aluminum and aluminum alloys comprised 32% of the structural weight of large bombers and transports in 1930, by 1934 the proportion had jumped to 76%.

Aluminum has no monopoly on a favorable strength-weight factor. We have cold drawn carbon steel wire, heat treated low alloy steel and stainless steel (cold drawn or heat treated). Each of them in turn has its own advantages which warrant its use in moving equipment, or in very large structures where dead load and bulk become unsupportable. In fact, aluminum cable can only compete with copper for high voltage transmission lines when steel-reinforced. Competition is particularly keen now between strong aluminum alloys and cold-rolled 18-8 for the construction of car bodies for high speed passenger trains; both have been used in a number of highly successful units. To quote an editorial in METAL PROGRESS for last April:

"Railroad operators, not being metallurgists, are more or less indifferent to the competing claims of these types. They are most interested in reliable equipment which will attract customers and be cheap to operate. It will no doubt take considerable time to determine the best answer for each region, road or division.

"If we consider the transportation industry as substantially stabilized, which of course it is not, we may obtain a general idea of the future demand for its construction materials. Locomotives and rail cars must be called upon to last about 25 years, and the new units are far in advance of the oldest 10%. Rebuilding will be more on the order of the 1935 or 1940 than that of the older equipment; hence, more light, strong metal (both ferrous and non-ferrous), will be utilized than obtains in the current structures.

"It even seems likely that the 1936 model motor cars, trucks, trains and ships will be regarded some years hence as having too little light metal for



Aluminum Castings Also Play an Important Part in High Strength, Light Weight Machine Parts. Photograph is frame and water jacket for diesel engine; it weighs 1640 lb., hardly more than half an equivalent iron casting. Courtesy Ingersoll-Rand Co. and Bohn Aluminum & Brass Corp.

economic operation. This forecast seems probable because the consumption curve of light metal in the transportation field has risen more steeply than in other fields during the last ten years, and this equipment has been purchased by those having the best knowledge of the true cost of transportation services."

More prosaic structures, like traveling cranes, derrick booms and steam shovel dippers, which do not travel so fast, and bridge floors, which do not travel at all, have been economically made of strong aluminum. An article on this phase of development was written by R. L. Templin for May 1935 METAL PROGRESS. After pointing out the ease with which heat treated shapes can be fabricated in the structural shop, using the conventional machinery, he emphasizes that section-for-section substitution of aluminum for steel is frequently very poor engineering practice. Economies must be found in collateral advantages rather than in first cost.

For instance, a 175-ft. boom on a 6-yd. dragline excavator was built largely of aluminum because each pound of weight saved on the boom saved two pounds of counterweight. It resulted that the same excavator was considerably safer against overturning and could operate faster with a 175-ft. aluminum boom than with a 150-ft. steel boom.

Aluminum for Bridge Floors

An even more interesting use of structural aluminum shapes is in the Smithfield Street bridge at Pittsburgh. This bridge had become seriously overloaded, but its expected life has been extended at least 25 years by replacing the old wrought iron floor system with aluminum, thus saving a little over one ton per lineal foot of bridge span. All load-carrying members of the floor system were of alloy 27-ST, which has a yield strength equal to that of silicon steel. The floor members are all painted with a primer (iron oxide plus zinc chromate) covered with two field coats of aluminum paint. The highway floor can now carry 20-ton, 4-wheel trucks, whereas loads had previously been limited to 13-ton trucks, and restricted traffic on the street railway tracks is no longer required. Cost of this job, including interest until bonds are retired, was $370,000, but it postponed for 25 years the building of a new bridge which would cost (including interest) in the neighborhood of $1,935,000.

A similar project for increasing the capacity of the historic Brooklyn suspension bridge is under consideration.

Development of new alloys and heat treatments in the last five years has not produced such spectacular results as a corresponding period in the 1920's. With the general field fairly well surveyed in a previous decade, more recent efforts have been toward perfecting certain alloys for specific purposes. Improved alloys for castings, forgings and strong structural shapes have made their appearance and been proven in use.

Alloy for Aircraft

For instance, the alloy now used almost exclusively for the structural members and highly stressed skin of the recent designs of aircraft is a modified duralumin, a "superduralumin," designated 24-S by the Aluminum Co. of America. It has the same nominal composition as duralumin (4% copper and a small amount of manganese, silicon and iron), but the magnesium content has been increased from 0.5% to 1.5%. Quoting J. B. Johnson, METAL PROGRESS, October 1935:

"The improvement in physical properties is worth while. The specification values for the new alloy are 62,000 psi. tensile strength and 40,000 psi. yield strength (both increases of 15 to 20%) with practically the same elongation. What this means to the airplane designer may be appraised by the statement that the saving in weight for one design in changing from duralumin (17-ST) to superduralumin (24-ST) was 150 lb., or approximately 4% of the structural weight. A frequency chart computed from tensile tests on specimens selected from every sheet used in a large production contract indicates that the uniformity of this alloy is exceptional. The standard deviation is approximately 1600 psi."

A more recent development is of a free-cutting screw machine stock by L. W. Kempf and W. A. Dean (see METAL PROGRESS for July 1935). Heat treated alloys of the duralumin type had, to a considerable degree, the properties of free-cutting stock — that is, "permitting machining at high rates of speed with tools having relatively large entrant angles, to excellent finish." However, a more freely cutting material was desirable, if it could be produced without damage to mechanical properties, hot-working characteristics and corrosion resistance. Several elements were found which conferred free-cutting properties; eventually a combination of them was devised, including a small

amount of lead and bismuth, together with enough copper for satisfactory hot working of the ingots and the development of mechanical properties in the rods by heat treatment.

Magnesium

Magnesium and its various strong alloys have been vigorously promoted, and so far the important applications have been for items where weight is a prime consideration. Examples are aircraft castings, landing wheels and instruments, parts for hand tools, moving parts of high speed and portable machinery, and even bodies for truck trailers. Foundry technique, both for sand castings and die castings, is somewhat specialized, but has been carefully and successfully worked out.

Sand castings have been used for aircraft engine starter housings since 1924, according to J. B. Johnson (METAL PROGRESS, October 1935).

"They are now used quite extensively for engine parts such as rear accessory cases and blower sections, oil pans, oil pumps, camshaft bearings and rocker box covers. The change to a magnesium casting for a rear section of an engine casing was responsible for a saving of 30 lb. in one noteworthy case. Some such castings have also been used for foot control pedals and for accessories on seats and floor, and for landing gear wheels. An aluminum-manganese-magnesium alloy with a tensile strength of 40,000 psi. in sheet and extruded shapes has been used in connection with fuselage cowling, seats and fairing. Such uses are more extensive abroad than here. In Europe magnesium alloys are frequently used for propellers, cowling, fuel tanks, and some structural members."

Copper and Its Alloys

In keeping with the intensive development of new light metal alloys, the copper and brass industry has also been studying its materials extensively. Important changes have been made in the fabricating mills, where the trend is toward more general use of extrusion, especially for larger and more intricate shapes, a relatively greater proportion of work in cold mills, instead of hot mills, and annealing in controlled atmospheres. Some interesting new alloys have been developed, especially those which age harden, others that resist corrosion better than the time-honored compositions, and still others especially adaptable for welding. All these developments are reflected in extensive additions to the non-ferrous section of Metals Handbook.

Copper alloys to meet severe requirements, either in fabrication or service, were discussed by D. K. Crampton in METAL PROGRESS last May. As to fabrication in present-day shops, the deep drawing of sheet and strip involves progressively more difficult requirements — a trend paralleling that for sheet steel discussed on page 117 of this issue. Most drawn brass articles must have a very smooth surface; inasmuch as a smooth surface depends on a fine grain size and deep drawing on a larger grain size, these two factors are mutually exclusive and a compromise must be made.

A second cause of difficulty in drawing and forming shops is the use of thinner and thinner gages, and (other things being equal) the thinner the material the less the depth to which it can be drawn. Next the trend is toward more complicated, intricate or angular designs, made without intermediate anneals except as a last resort.

Such requirements as these are met not with new alloys but a more precise mill control of quality, Mr. Crampton points out. Copper content is important, and after the general type of brass is selected, the two impurities lead and iron are kept below 0.05% each. (On severe forming, lead tends to cause cracked edges; iron, even in small amounts, appreciably hardens all copper alloys.) Next to composition, accurate control of "temper" is important.

"Annealed temper is commonly defined by the trade in terms of grain size. Formerly a considerable variation in grain size was quite common, due to lack of suitably controlled annealing furnaces in the mills. Modern furnaces, however, are capable of much more accurate control. For most work under present conditions, the permissible range calls for an upper limit of about twice the lower limit; for instance, a range of 0.015 mm. to 0.030 mm. grain size, or perhaps 0.025 mm. to 0.050 mm. grain size would be supplied. Where necessary, it is possible to keep within a range where the upper limit is not more than one and one half times the lower.

"Surface texture and condition of the material become increasingly significant as the operations performed become more drastic and complicated. It is found that complete freedom from all traces of dirt, thin oxide films, and traces of acid from pickling must be eliminated. The surface texture as controlled by the condition of the rolls and the degree of anneal and care in pickling is also very important. Finally, a good lubricant uniformly applied and a nice adjustment of forming tools frequently determine the success or failure of a given operation. Many types of lubricants can be

...rior of Room for Today's Living, Designed by Archi-...d Brown. Metal furniture utilizes "Ambrac," copper-...kel-zinc alloy. Photo courtesy American Brass Co.

used but none appears better and more economical than a heavy soap solution made from a good grade of chip soap."

Selection of copper alloys to resist specific types of corrosion was also discussed by N. W. Mitchell in the December 1935 issue. Selective corrosion ("dezincification") of brass condenser tubes has given much trouble for at least a generation. Oxygen concentration cells (the supposed villain in the 18-8 pitting type of corrosion) are responsible for waterline attack so frequently noted in brass tubes and shells, and for "deposit attack" or pits under lodged particles. A third source of trouble is impingement of water which causes the collapse of "vacuum bubbles," and the water-hammer continually scours off the naturally forming surface film, permitting unrestricted corrosion at such bare spots.

If the composition of the alloy is carefully selected according to the corrosive surroundings, much can be done to mitigate the above troubles. Broadly speaking, red brass with 85% copper has the maximum resistance to sea water and many other solutions. It will not dezincify under any conditions known to Mr. Mitchell, being in that respect superior to admiralty metal (70% Cu, 29% Zn, 1% Sn). The latter — once the favorite for marine condensers — is unable to withstand impingement attack; aluminum must be added to form an adherent, self-healing film and hence the aluminum brass (76% Cu, 22% Zn, 2% Al) has been marketed. Even better is the "bronze"— 82% Cu, 15% Zn, 2% Al, 1% Sn, which is better because it is also immune to dezincification as well as impingement attack.

Special Alloys for Oil Refineries

In oil refineries attack from corrosive waters is intense and in addition there is severe corrosion from sulphur compounds in the oil. In general, attack on the oil side of a tube will result in extensive pitting; frequently the individual pits are so close together as to give a honeycombed appearance. It is found that most alloys well suited to resisting water are not too well suited to resist attack from oil, and vice versa. Where, as is frequently the case, oil or oil vapor is in contact with one side of the tube and corrosive water with the other, it is necessary to provide an alloy resistant to both, and this is composed approximately of 92% copper, 4% nickel and 4% aluminum.

Copper-nickel alloys containing high nickel (20 to 30%), although greater in first cost, have been exceedingly long-lived in marine condenser service. The Queen Mary, for instance, has four main condensers, each with 14,000 seamless tubes of the 30% nickel alloy; the Normandie also uses a comparable number. Some installations can work on a smaller factor of safety, and a somewhat less expensive alloy containing 20% nickel and 5% zinc will be useful; the zinc acts as a deoxidizer, influences the grain size, and increases the workability almost to that of yellow brass. Alloys containing from 20 to 30% nickel have, in Mr. Crampton's opinion, greater all-around resistance to more types of corrosive water than any other commercial alloy. In addition they are excellent for atmospheric exposure (screen cloth, exterior metal trim) and all hardware and fixtures exposed to fumes, smoke, salt and various chemicals.

These copper-nickel alloys containing a little zinc might properly be classed among the nickel

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silvers. Such copper-nickel-zinc alloys ("german silver") have been available for a long, long time in a wide range of analyses, ranging from 5% to as much as 30% nickel, and in almost an infinity of shapes and surface finishes. Perhaps the 18% alloy is of most general utility for drawing, spinning, tableware, hollow ware, and a base for silver plated ware. Its color blends well with the silver should the plating wear off. The copper and zinc proportions vary generally from a 65:17 ratio to one with considerably more zinc; the high copper being better for difficult fabrication and corrosion resistance; the higher zinc being better for spring qualities and electrical resistance. As in many other varieties of commercial alloys, special additions (in this case lead) are made to improve machinability. Extruded forms are made of remarkable complexity for architectural purposes and for the jewelry and hollow ware trade, a suitable alloy having about 13% nickel, 1.5% lead and almost equal parts of copper and zinc.

Copper-Silicon Alloys

A great amount of interest in the silicon-copper alloy has recently been aroused. Cyril S. Smith ⊜ contributes an article to the new Handbook on the binary alloy diagram, which has been intently studied by physical chemists because of its complexity in the region 5 to 14% silicon, although small commercial use has resulted. The recently developed rolling mill alloys contain about 3% silicon with about 1% of either zinc, tin, manganese or lead — each important producer seems to have his own ideas as to which one is best. H. C. Jennison, W. R. Hibbard and E. E. Wachsmuth ⊜ describe the properties of two of these varieties in Handbook articles. They have the strength of medium steel, the corrosion resistance of unalloyed copper, good drawability in sheet or strip form and excellent surface appearance. Welding properties are unusually good for copper alloys. They are widely used for electrical apparatus and transmission line fittings, fasteners of all kinds, range boilers, ducts and equipment for ventilating and air conditioning.

Bearing metals of this family usually contain about 80% copper, 5% silicon, and 15% zinc — an alloy which is also suitable for pressure die castings.

Stainless Steel

of the

18-8 Variety

An Editorial Review

Courtesy Carnegie-Illinois Steel Corp.

One of Twin, 600-Gal. Tanks for Fruit Juices, to Operate Under Vacuum, Installed at Bireley's California Fruit Products, Los Angeles, Calif.

IT IS WELL KNOWN that stainless steels were first developed in the cutlery trade, and the name is quite appropriate. These high chromium, high carbon alloys of iron are **steels,** capable of being hardened, tempered and ground to a durable, keen edge; they are also **stainless,** resisting tarnish in all manner of food stuffs, in industrial atmospheres and at the seashore.

In the intervening years almost the entire chromium-iron-carbon system, to say nothing of the chromium-nickel-iron-carbon system, has been exploited as "stainless steel." This is too bad, for some of the alloys marketed are not hardenable, many of them are intended for high temperature use where they acquire a dull oxide coating, and some of them are not even hardenable steels.

To limit this discussion we will confine it to the so-called 18-8 type, basically 18% chromium more or less, 8% nickel more or less. This type is far and away the most important in the American industry, comprising one quarter of the round 100,000 tons of heat and corrosion resisting alloys made in America last year. Naturally it has received the most study by both producers and consumers — as well it might, since it is a remarkable alloy, different in many ways from the familiar carbon and low alloy steels. It is what scientists call a metastable alloy. All the alloying elements enter solid solution in iron at high annealing temperatures and are retained as such after fairly rapid cooling. In this condition, a single-phase austenitic alloy, it is soft, ductile, non-magnetic, and highly inert to chemical attack under oxidizing conditions. Unfortunately even the quenched low carbon varieties have enough atomic mobility in the range from 1600 down to 800° F. for the austenite (gamma iron) to transform to the truly stable ferrite (alpha iron) and precipitate some insoluble compounds (complex carbides). More unfortunately still, these carbides do not scatter themselves uniformly through the metal and strengthen it — as would happen in a plain carbon steel — but accumulate at grain boundaries where they embrittle the alloy and make it vulnerable to corrosive attack.

Most of the difficulties in manufacture and use have been caused, directly or indirectly, from such changes in microstructure occurring at moderate temperature during manufacture, fabrication or use, and every new user must have the facts drilled

into him so he may avoid trouble. So much is necessarily said along these lines that there is danger of obscuring the fact that troubles are rare in proportion to the successes, and that hundreds of thousands of tons of 18-8 are acting perfectly in a multitude of situations entirely impossible for any alloy known 20 years ago.

Its present popularity and importance have been achieved by virtue of the fact that its peculiar advantages (corrosion resistance, ease of fabrication, durability and general adaptability) considerably outweigh its inherent disadvantages. One among these is cost, and a factor that frequently turns the scale against the alloy to one frankly less satisfactory. Most applications in the automotive industry, for instance, are decorative. If it is cheaper to stamp parts from brass or soft steel or make die castings, and then put a chromium plate on them that will last for two or three years, than it is to make the parts of paper-thin stainless, the plated ware gets the order. It is to be noted, however, that wherever the bright work is constantly under the driver's eye — as in a banjo-type steering wheel or in a hinge on the engine hood — stainless is the rule.

What can be done about this matter of cost?

Factors Responsible for High Cost

A discussion of this important problem was contained in an editorial last June. Base price on 18-8 bars is 23¢ per lb. as compared to 6¢ for common S.A.E. analyses and 2¢ for soft steel. Sheet and strip with special treatment and finish may even approach the 55¢ per lb. of high speed tool-steel. Several factors come in here, among which may be mentioned cost of raw materials, steel mill costs, cost of selling and development costs.

Alloy costs are undoubtedly high. Low carbon ferrochrome is quoted at 20¢ per lb. of contained chromium, and electrolytic nickel at 36¢ per lb. One readily figures about 8¢ for alloy in a pound of 18-8 in the ingot, allowing for slag losses of chromium during melting.

Some earnest efforts have been made to produce low carbon stainless steels from cheaper, high carbon ferrochrome or even from chrome ore, but the problem still remains a difficult one. Eventual success in replacing much of the chromium and nickel in the alloys with other cheaper elements might be responsible for a saving of 1 or 2¢ in raw material costs in the ingot, which, while not much, is something. At any rate, alloy costs will always remain comparatively high.

Many items of special mill practice are responsible for excessive scrap losses and high mill costs. The greatest single charge is the cost of a lustrous finish on sheet and strip. As much as 10¢ a pound could be saved whenever durability rather than beauty is the prime requirement and the material ordered in the as-rolled condition. Selling, warehousing and shipping costs also run high. When customers are educated about how to handle these new steels successfully, and when they buy them in larger quantities to definite specifications, all these costs will take a sharp drop. Lower selling prices in turn will undoubtedly open up wider markets, thus starting a favorable cycle whose end can only be guessed at.

Economy of Bimetals

In order to cut down the cost of large equipment made of solid stainless, various types of bimetals or metal-clad have been promoted. Some very large welded retorts and stills of carbon steel have also been completely lined with thin stainless sheets, spot welded to the main structure on 1-in. centers and fusion welded edge to edge.

Several methods of manufacturing clad metal are in vogue. One is to place two plates of corrosion resistant alloy face to face and seal the edges all around by welding. Then this is placed centrally in an ingot mold, molten steel cast around, the composite ingot rolled down, and edges sheared so that the finished plate separates into two composite pieces. Another is to start with a composite slab made of stainless steel facing and carbon steel backing, with a thin sheet of carbon-free iron between, heat in a reducing atmosphere, and weld all three together by rolling at a proper temperature. Still another is to plate the pieces with electrolytic iron on faying surfaces before heating for rolling and forging. Another builds up a deposit of stainless alloy by electric welding on a slab of carbon steel, reheats and rolls this to shape.

Pure nickel, 18-8, and the 14% chromium steels are commonly used for facing low carbon flange steel or one of the low alloy, high strength structural steels. Much of it has been used for tankage in the chemical, soap, textile, and food processing industries, and pressure vessels for petroleum refining. The desire is to reduce corrosion losses in the plain steel with cheaper material than solid alloy.

One of the largest recent applications, where 150 tons of clad steel plate were fabricated into a large diameter air main for a sewage disposal plant, foreshadows what will probably be a large future use of thin clad sheet, namely, in ducts for air conditioning systems where a little condensed water vapor perforates plain steel sheet in a very few months. Clad steel also has great possibilities in reducing corrosion losses in tanks storing corrosive petroleum.

It will be recalled that the austenitic stainless steels were discovered by Messrs. Strauss and Maurer in Germany prior to the war. From a survey of the chromium-nickel-iron system two alloys

were patented having interesting tensile properties, chemical resistance and manufacturing possibilities. One of them was a group designated as "VA," containing in the neighborhood of 20% chromium, 7% nickel and 0.25% carbon. Some idea as to how the low-carbon 18-8 proportions were adopted can be had from the following quotation from a letter to the Editor from Benno Strauss dated May 30, 1936:

"Raising the chromium content to about 20% slightly increases the resistance to nitric acid and oxidizing agents, but not sufficiently, in our opinion, to compensate for the increased cost of the chromium content. On the other hand, our experience indicates that chromium content should not be reduced under 17%, for then the resistance to severe chemical corrosion requirements is diminished. We therefore favored about 18% chromium.

"The following might be said on the influence of nickel: With the increasing nickel content the resistance to reducing acids, such as sulphuric and hydrochloric, is increased somewhat, although it is not necessary to go over about 12%. This improvement, however, has not been so great as to lead so far to any practical application of the higher nickel alloys. At the same time the resistance to nitric acid of the higher nickel alloys is lowered, so that we believe the most favorable composition to be 7 to 9% nickel. This percentage of nickel also provides the desired austenitic structure.

"If the carbon content of the chromium-nickel steels is raised, no resistance to intercrystalline attack is provided, even though the chromium and nickel may be in the upper limits.

"On the subject of workability the following facts are known: A 20-7 alloy with higher carbon content is not quite so soft and ductile (tough) as a 16-10 alloy. Moreover, marked hardening of the first-mentioned steel occurs on cold working and at the same time a marked increase in magnetism.

"On the basis of the above considerations, we believe that a steel with about 18% chromium and 8 to 9% nickel best meets all technical requirements and naturally is more economical than a steel higher in chromium and nickel."

Modifications of 18-8 Analysis

What happens when these somewhat standardized proportions are slightly deviated from? The most thorough discussion of this (and this is restricted to cold working properties) is given in a paper for the 1936 convention by V. N. Krivobok, R. A. Lincoln and Robert Patterson, Jr., of the research department, Allegheny Steel Co. It covers the range in analysis from 17% chromium, 7% nickel to 20% chromium, 10% nickel in two carbon contents, 0.05 and 0.14%.

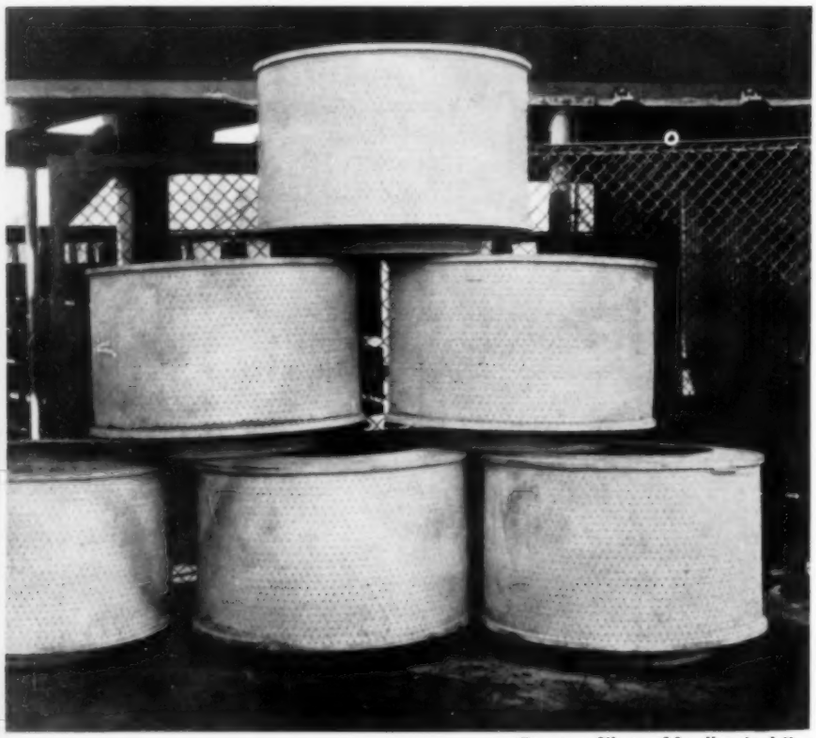
When these metastable austenitic alloys are cold worked, as by cold rolling, wire drawing, or even bending, some of the mobile metal at slip planes will transform to the stable ferritic phase, precipitating carbides there which harden the alloy by stopping further slip. This transformation during cold working is the more noticeable as the composition of the alloy is further from the borderline where austenitic phase is the truly stable phase at room temperature. Since the low carbon alloys of 20-10 analysis are nearest to stability, wide variations in work hardenability were expected and found, as the analysis was varied.

Some representative figures are quoted in the adjoining table. A study of this table will indicate

Properties of Alloys of 18-8 Type When Cold Rolled From Annealed 0.038-in. Sheet

Min. Radius of Bend	Analysis			Reduction by Cold Working	Tensile Properties		
	Cr	Ni	C		Ultimate Strength	Proof Stress	Elongation in 2in.
Cold Rolled to 150,000 psi.							
0.9 t	17.2	7.2	0.14	10%	152,000	50,000	53.0%
0.9 t	15.7	7.5	0.10	5	157,000	—	32.0
1.35 t	17.6	8.6	0.13	34	153,000	—	19.0
1.5 t	17.2	7.1	0.05	10	156,000	41,000	15.0
2.1 t	17.7	9.8	0.05	37	150,000	—	10.0
2.5 t	18.2	9.1	0.05	47	152,000	100,000	5.0
Cold Rolled to 175,000 psi.							
1.0 t	17.2	7.2	0.14	16	173,000	62,000	35.0
1.5 t	15.7	7.5	0.10	16	174,000	—	23.0
2.2 t	18.6	8.2	0.05	40	173,000	—	7.0
3.3 t	17.2	7.1	0.05	29	182,000	110,000	9.0
4.1 t	16.8	9.8	0.05	55	171,000	90,000	2.0
Cold Rolled to 200,000 psi.							
1.2 t	18.0	7.0	0.14	29	202,000	—	22.0
1.9 t	17.2	7.2	0.14	30	201,000	120,000	20.0
3.0 t	15.7	7.5	0.10	21	197,600	—	15.0
4.3 t	18.7	7.3	0.06	45	207,000	146,000	4.0
Cold Rolled to 225,000 psi.							
2.2 t	17.2	7.2	0.14	40	225,000	120,000	12.5
3.2 t	18.7	7.3	0.06	58	226,000	—	2.5

that, in general, the higher carbon alloys (0.14%) give better ductility than the low carbon alloys (0.06%) when cold rolled to equivalent tensile strengths. This is true when ductility is gaged either by elongation or minimum bend, and these properties are achieved with much less cold rolling. This is as to be expected, as carbon is a good strengthener even in the annealed condition, and the higher carbon austenites, being further from the correct analysis for stable microstructure, transform and harden more copiously during cold work. Good bending properties, therefore, can be had at all ultimate strengths with a moderate amount of cold work using alloys comparatively low in nickel and chromium (17-7) and high in carbon (0.14%). Should corrosive conditions in service be so severe



Courtesy Electro Metallurgical Co.

All-Welded Stainless Steel Centrifuge Baskets for Corrosive Solutions and Materials. Statically and dynamically balanced; strong, light, enduring

as to demand minimum carbon (0.05%) high strength and reasonably good bending properties can be achieved by rather heavy cold rolling of the higher alloys (18-9 or 19-9).

Krivobok and his associates also find that in the low carbon series the annealed strength and hardness decrease greatly as the nickel is increased. Thus a 17-7 has 132,000 psi. and 22% elongation whereas a 17-10 has 85,000 psi. and 62% elongation; corresponding strengths for 18-7 and 18-10 are 125,000 and 85,000 psi. respectively. Furthermore, the 17-9 to 19-9 alloys work harden at a materially lower rate than their 17-7 to 19-7 counterparts. This will indicate sound reason for raising nickel and lowering chromium when a soft alloy is desired for spinning into various utensils and cold drawing into fine wire. (Metallurgically, the reason is found in the fact that as chromium goes up, relative to the nickel, some delta solid solution is formed, which is usually avoided by metallurgists because it has such different hot forming and work hardening properties from the associated austenite.)

Many sales arguments could be collected for the existing minor variations from these conventional 18-8 proportions now on the market, based on such sound metallurgy as Dr. Krivobok's, steelmaking technique, patents, prices, proprietary specifications and commercial policy. As a matter of fact, the steel melter is very uncomfortable when held to too-close limits in nickel and chromium, and the Editor suspects that a potent reason for the 19-9 analysis is that it is "shot at" in order to meet an 18-8 **minimum** analysis (imposed by many users, especially in the dairy industry, following the lead of the U. S. Navy, on the basis that it has a worthwhile increase in corrosion resistance).

Fundamentally New Analyses

Another attack on the matter of costly alloys is being made by substitution of lower-priced ennobling elements such as silicon or aluminum and austenizing elements such as manganese. Much investigation has also been given the hardening elements such as boron and nitrogen and softening elements such as titanium, tantalum and columbium, although cheapness is not an expected advantage of this category.

An alloy with 16% chromium, 6% nickel and 4% manganese is reported already in production in the United States. It is called "16-6." Another is 16.5% chromium, 8% nickel and 1.25% manganese. Both of these have sufficient tarnish resistance to be suitable for automotive and architectural trim, and sufficient ductility for deep drawing operations.

Substitution of manganese for nickel has been pushed to its limit by the Germans, and recommended by a leading metallurgist in this country. Success abroad has been had only in the less exacting uses, as indicated from work by P. Schafmeister of Krupp's staff, quoted in **Metal Progress** for June.

"Manganese is not as potent as nickel in changing the body-centered ferrite of chromium-iron into face-centered austenite, and it is therefore necessary to put in proportionately more of the alloy than of the nickel it replaces and also to raise the carbon content. Under certain conditions considerable delta iron (ferrite) is formed, but neither the delta nor the gamma solid solution seems very stable on long annealing. An iron-chromium compound, first observed in 1927 and called "B constituent" by E. C. Bain and W. E. Griffiths will precipitate in these manganese steels at 900 to 1500° F., and as this is hard and brittle it causes considerable loss of ductility and the steel is not useful in that temperature range. Since corrosion resistance in boiling HNO_3 is lower, as well as oxidation resistance, the Cr-Mn steels cannot be regarded as having the same excellent properties as 18-8 Cr-Ni, and direct substitution cannot be made."

On the other hand, A. B. Kinzel of Union Carbide & Carbon Corp., suggests the advantage of both manganese and copper additions. (See **Metal Progress**, March 1936.) Even though substitution of manganese for nickel, weight for weight, will form a duplex microstructure containing both ferrite (α-δ iron) and austenite (γ iron) this, in his

opinion, is not altogether a detriment, as he points out that "melting practice is favorably affected by the well-known property of manganese oxide to form fluid slags with silicates and chromium oxides, so that chromium steels with manganese are much more free from inclusions than those without it.

"At forging temperature, the steel consists of a fine-grained aggregate of chromium austenite and chromium ferrite, and ferrite facilitates hot work. Both theory and experience demonstrate greater ease of reduction from ingot to final hot-worked product of the two-phase chromium-manganese-copper steels.

"In cold rolling and the production of stamped and formed articles, austenite, being fundamentally more ductile than ferrite, permits greater plastic deformation than ferrite before fracture occurs. However, in machining operations the austenitic steels are notably more difficult to machine than the ferritic steels, and the chromium-manganese steel with 60% of its microstructure austenitic is somewhat more readily drilled, reamed and cut than the 18-8 fully austenitic steels.

"In welding several factors are involved. The ability of the metal to flow freely, protected by a slag sufficiently fluid to facilitate the operation is the first factor. Chromium oxide and slags high therein are highly refractory. This refractoriness is reduced markedly by manganese oxide. Thus, the welding of a chromium-manganese steel is a simple operation.

"The next factor involved in welding relates to intercrystalline corrosion. This phenomenon is directly related to a change in the austenite and does not occur in ferrite. Thus, with a steel containing 60% austenite and 40% ferrite only a portion of the matrix is affected. Actual tests on welded chromium-manganese steel have shown that the time at temperature is so short that while the material is rendered susceptible to attack by acidulated copper sulphate solution, the degree of susceptibility is low, and less aggressive corroding mediums do not render the material unserviceable from the engineering standpoint. Impact test specimens show small loss in toughness.

"Many welded structures of chromium-manganese steel have now been in service for several years that were not annealed after welding, and there has been no difficulty with any of them. (These steels are not advocated for service involving long exposure to relatively high temperatures combined with attack by an aggressive corrosive medium.)"

Mr. Kinzel goes on to discuss the effect of copper in these steels, called by him the 18-8-1 (Cr-Mn-Cu) steels:

"First, copper stabilizes the austenite and increases the equilibrium range without appreciably increasing the amount of austenite formed. Second, it tends to promote the formation of protective surface film when the alloy is subjected to corrosion conditions of low oxidizing power. These steels have proved to be equal to or better than other stainless steels of equivalent chromium content when exposed to atmospheric and salt water corrosion. Specific illustrations are the four photographs of test strips reproduced below.

"Other corrosion resistance tests indicated no attack in cold 20% nitric, in boiling 10% nitric, in cold 10% oxalic and in boiling 10% phosphoric acid. It is immune to boiling 10% sodium, calcium, or potassium chloride. No attack was evident in lemon juice, orange juice or cider at room temperature, or in canned rhubarb or canned tomatoes at 100° C. Moreover, the resistance of the alloy to corrosion in a moist atmosphere of sulphur dioxide at 1700° F. was of a relatively high order with complete freedom from pitting. The material is slightly attacked by cold 10% sulphuric plus 2% nitric acid, and by boiling 10% oxalic acid."

Specimens Exposed One Year in Air at 180° F., Relative Humidity 92%

Specimen at left has 18% Cr, 0.40% Mn, 0.10% C and had fairly good resistance to this hot, humid atmosphere; next had 18.2% Cr, 8.6% Ni, 0.46% Mn, 0.07% C and presented good resistance; the next one analyzed 17.9% Cr, 9.5% Mn, 0.90% Cu, 0.07% C and was very resistant; whereas the one at the right end had 17.8% Cr, 6.1% Mn 3.8% Ni, 0.95% Cu, 0.07% C and was practically immune to corrosion

Pitting Type of Corrosion

Mention of the corrodibility of austenitic 18-8 in salt water brings to mind a second defect in these alloys which caused much trouble, and indicates a field of application that must be avoided until the cure is found. This refers to the pitting type of corrosion in stagnant salt water or in brines containing chloride ions. An analogous type of trouble has been found at faying surfaces and has been termed "contact corrosion."

Unexpected corrosion of 18-8 had already been encountered sporadically in such widely different applications as petroleum refineries, paper pulp digesters, milk coolers, and hospital ware. However, it did not attract much engineering attention until news came of serious troubles with gasoline stowage tanks and firelines on naval vessels. This equipment was in contact with sea water, more or less fouled with marine organisms or diluted sewage, and in both situations stainless steel was penetrated by pitting in as short a time as six months.

Such facts as could be discovered about this matter were presented in an editorial survey in **Metal Progress**, February 1935. It was concluded that the trouble was either due to "contact corrosion" under non-metallic substances (either scale or inclusions), or under solid particles brought in by the water, or to corrosion by "oxygen concentration cells" existing in porosities and pits or caused by lodgment of live organisms or dead organic matter which has a reducing or deoxidizing nature, or even in moisture penetrating or condensing between the faying surfaces in lapped seams. As yet it is impossible to diagnose this particular trouble because it has been so difficult to reproduce under laboratory conditions, or even to cause pitting corrosion except with quite special reagents, such as ferric chloride and sodium hypochlorite.

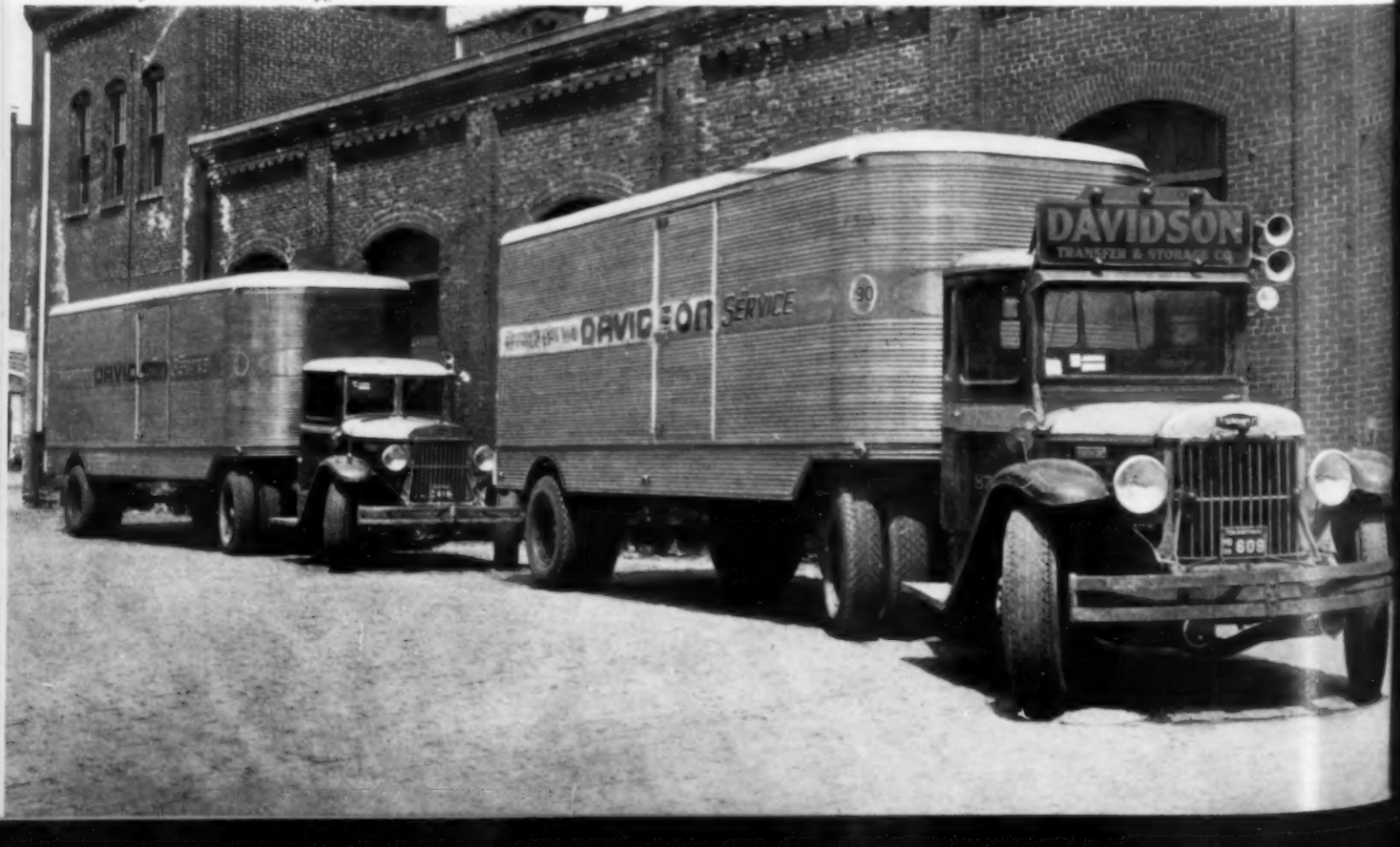
The available evidence points to irregularities of some sort at the surface as the locus of the pit, where the normal protective coat of oxide is broken and prevented from re-forming and attaching itself.

Chromium and iron-chromium alloys have a high **initial** rate of oxidation, but an impervious and adherent layer of transparent oxide a few molecules thick forms almost instantly and slows the rate of oxidation down practically to zero. This protective coat, once broken, will heal itself promptly if there is any free oxygen in the vicinity, but in places where the oxide coating is dissolved faster than it can form (as in hydrochloric acid) corrosion proceeds very rapidly. A particle of decaying organic matter which reacts with all the available oxygen in the surrounding water, leaving none to join with exposed chromium and iron, may very well be one of the proximate causes of a pit.

Whether pitting, once started, can be stopped will be questioned by a believer in corrosion by oxygen concentration cells. This type of corrosion may start immediately wherever there are porosities of small cross-sectional area in proportion to their depth. Under such circumstances, the electrolyte in the bottom of the hole becomes poorer in oxygen than at the entrance, the oxygen-poor area

Light Weight, Stainless Steel Refrigerator Trailers for Hauling Dairy and Meat Products Between Baltimore and New York. Floor is a one-piece stainless steel pan, with 6-in. flanges at sides thus preventing moisture from entering insulation below

Photo Courtesy Edward G. Budd Mfg. Co.



is anodic to the other, and an electrolytic cell is formed. The products of corrosion (iron, chromium, and nickel ions) are carried to the cathode, that is, to the entrance of the pit, where they oxidize; even if they deposit there, they are unable to protect metal at the bottom of the pit from further attack with the result that corrosion continues until the metal is perforated. If such action takes place in chloride solutions, one of the products — ferric chloride — will greatly intensify it.

Such troubles may possibly be cured by changing the composition of the alloy, such as the addition of manganese and copper as suggested by Mr. Kinzel, or the 18% chromium, 2% nickel steel utilized by the British Air Ministry for seaplanes. Unsatisfactory experiences with 18-8 in both the woolen textile industry and the paper and pulp industry have been cured by adding 3% molybdenum to the alloy. Pitting of 18-8 in contact with calcium chloride refrigerants has been prevented by the use of low carbon metal and neutralizing the solution by simply immersing a bag of lime in the circulating system. Even in so simple an application as architectural trim, 18-8 will rust and pit if building filth attaches itself — but in the most severe case the original color can be readily restored by washing with Bon Ami, and rusting and pitting do not re-occur on the finished structure. When all is said and done, however, the pitting of 18-8 in sea water and salt solutions is still an unsolved problem.

Welding Practices

A third difficulty experienced with 18-8 may be dismissed rather briefly, as its cause and a number of cures or palliatives are so well known. This difficulty has to do with impaired corrosion resistance at and alongside welds (and it should be emphasized that this causes damage only in severely corrosive surroundings, such as strong acids). It has been amply proven than this corrodibility is due to the precipitation of intergranular carbides from the austenite during the time the metal is heated to temperatures between 800 and 1600° F. The most obvious cure, therefore, is to add enough strongly carbide-forming elements, such as titanium, tantalum or columbium, to the base metal and welding rod to lock up the inevitable carbon in an inert compound which is in effect an inclusion, since it does not go into and out of solution as would an iron or chromium carbide. Such stabilized alloys and welding rods are on the market. The effect of columbium in the analysis has been discussed by W. J. Priestley, Vice-President, Electro Metallurgical Co. in **Metal Progress** last December.

Another interesting development in this direction is mentioned by J. H. G. Monypenny of Brown Bayley's Steel Works, Ltd., Sheffield, England, in a letter to **Metal Progress** last June: "In the production of steels free from intergranular corrosion effects (or 'weld-decay-free' steels, as they are often called), the contribution of our own firm has been the use of silicon (up to 6%). We are regularly producing steel under this patent which is quite free from troubles due to 'weld decay.'

"The silicon content of the steel has other very definite advantages; for example, it increases markedly its resistance at high temperatures to oxidation and to the attack of many acids. Again, it is well known to be difficult to produce a deposit of weld metal that will be free from intergranular corrosion when using a steel 'stabilized' with titanium, owing to the readiness with which this metal is oxidized; silicon is much less readily oxidized and there is no difficulty in producing deposits of weld metal from the high silicon 18-8, which are themselves free from intergranular corrosion."

It is also possible to modify the welding method, using a special type of resistance spot-welder, wherein the pressure, current and its duration are carefully limited so as to heat a minimum of metal at the contacting surfaces and therefore keep the temperature at the exposed metal faces below the dangerous 800° F. This is the essence of "shotwelding," utilized so widely in the fabrication of thin stainless sheet into load-carrying structures such as aircraft, deckhouses and bulkheads aboard ships, passenger cars, truck and trailer bodies.

Fabricated Stainless in High Speed Structures

The success of high speed trains, diesel-powered, is the important news of the industrial world today. For this, as in all similar situations where the cost of hauling dead weight around is a controlling factor, parts fabricated of stainless steel sheet come in competition with the strong aluminum and magnesium alloys and with heat treated low alloy steel. Effective use of any of these involves careful design along entirely new principles, and in general stainless steel becomes competitive only in members and structures resisting rather heavy loads. This is indicated by Wilson L. Sutton, Chief Engineer, Fleetwings, Inc., in his article in **Metal Progress** for June:

"A comparison of the properties of the two metals, aluminum and 18-8, indicates that there is little advantage, one way or another, to guide the designer in making a selection. The applied loads on the structure should be of such magnitude as to utilize a fairly heavy gage of stainless steel and by so doing minimize the local buckling and elastic failures. This premise points toward large air-

planes as the best structures for stainless. They are heavily loaded and require a minimum of cross-section for maximum aerodynamic efficiency. In the small airplane as usually constructed, the selection of stainless steel would be limited by the minimum gage obtainable from the rolling mill and the stability of the part made from these thin sheets, rather than by the stress requirements. As the size and loading increase, the thickness of metal reaches the figure where a better form factor and the utmost efficiency can be realized through the use of heavier sections and less closely spaced stiffeners.

"The one marked advantage that stainless steel has over the strong aluminum alloy is in its fabrication, since all joints can be made by very fast spot welding rather than riveting. The unit cost of spot welding is materially less than riveting and has numerous advantages from an airplane designer's point of view. Overlapping shotwelds form a seam weld and a watertight joint, which when used in seaplane construction results in an extremely efficient method of closing the seams, completely watertight and requiring no caulking material on the faying surfaces and around the rivets, thereby resulting in a less weight for the seam itself."

(While not wishing to be an old gloom, the Editor thinks it well to call attention to the possibility of "contact corrosion" at these seam welds. Can they be so tightly and completely welded that there is no possibility for the capillary entrance of moisture?)

Stainless for Buildings

This rather lengthy review may well conclude with some notes on the use of stainless in architectural works and objects of art. Oscar B. Bach, a leading American artist, finds in stainless steel a medium unexcelled for creative work of enduring beauty (**Metal Progress** for June). M. J. R. Morris and Karl Kautz, of the Republic Steel Corp. staff, sum up the architectural situation as follows:

"Several advantages of stainless steel as an exterior covering for buildings may be cited, principal among which are that it is rustproof, noncorroding, and permanent. It will not tarnish nor become dull when exposed to atmospheric agencies and its gleaming beauty is unequaled. It is available in many finishes, varying from mirror-reflecting to a frosty silvery tone. It cannot chip, crack, or wear thin; it is not plated but the same metal all the way through. It can be cleaned easily of any lodgment of dirt or grime with soap and water or various commercial cleaning solutions. One of its outstanding characteristics is the ease with which it can be fabricated by drawing, punching, shearing, riveting, welding, soldering, brazing, and silver soldering. These facts have been proven by the extensive use of the 18% chromium, 8% nickel alloy for exteriors on several sky-scrapers—constructions which have received much publicity."

Doubtless a more important tonnage has gone into smaller buildings and even rebuilt store fronts. It is giving most satisfaction in the latter cases, where it can be washed easily, for curiously enough, architects and owners have acquired the notion that stainless steel should remain bright and gleaming indefinitely even when showered with the dirt, soot, smoke and fog of a densely populated city. They are willing to wash windows and window trim frequently, but not the broader expanse of exposed bright metal on pilasters, walls and towers.

This represents a temporary mental aberration, however, for even after years of neglect, the first metal to be used externally in sky-scrapers has only acquired a slight dullness of color and some black and streaked stains or deposits at the horizontal jointures of the metal. In the opinion of candid architects, "this is not altogether detrimental, for it has rather heightened the effect, as the metal has been treated so broadly and placed so far above the eye of the observer that the luster is quite apparent and the loss in subtlety of surface texture is not noticeable from the street level. Furthermore, the dark deposits at the joints serve to emphasize the type of material used, by showing clearly the method of joining."

An Ancient Four-Story "Walk-Up" Had Its Face Lifted With the Aid of Stucco, Black Glass and Stainless Steel